

Mineral Resources of the
Charlotte 1°×2° Quadrangle,
North Carolina and South Carolina

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1462



Mineral Resources of the Charlotte 1°×2° Quadrangle, North Carolina and South Carolina

Edited By JACOB E. GAIR

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1462

*Evaluations of 17 types of metallic-nonmetallic mineral
deposits and of stone, sand-gravel, and clay construction
materials, with geologic, geophysical, and geochemical
background information*



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MINERAL RESOURCES OF THE CHARLOTTE 1°×2° QUADRANGLE, NORTH CAROLINA AND SOUTH CAROLINA

Edited by JACOB E. GAIR

INTRODUCTION

By JACOB E. GAIR

THE CONTERMINOUS UNITED STATES MINERAL ASSESSMENT PROGRAM (CUSMAP)

This report is the product of a 4-year project of the U.S. Geological Survey (USGS) under the Conterminous United States Mineral Assessment Program (CUSMAP) to assess mineral resources of the Charlotte 1°×2° quadrangle, North Carolina and South Carolina (fig. 1). Data on geology, mineral-deposit occurrences, geochemistry, heavy minerals, and geophysics available in September 1981 have been integrated into a multidisciplinary analysis of the mineral-resource potential of the quadrangle. In addition, the relative importance of different commodities of the area is evaluated from records of past production through 1978. The results of CUSMAP for the Charlotte quadrangle are presented here and in related map reports of the U.S. Geological Survey (see Gair and others, 1986). Stone, sand and gravel, clay, and 17 types of metallic and other nonmetallic mineral deposits are evaluated. Commodities produced from these deposits at the present time or in the past, or those judged potentially available, are base metals (copper, lead, and zinc), gold, silver, lithium, tin, beryllium, iron, thorium (monazite), rare earths, zirconium, barite, sulfur, feldspar, mica, corundum, kyanite and sillimanite, quartz, and rutile.

The general arrangement of this report and the plan for the resource assessment follow rather closely the outlines of several earlier CUSMAP reports, particularly the report on the Rolla 1°×2° quadrangle, Missouri (Pratt, 1981). The methods of mineral-resource assessment used in that report, and generally followed here, were evolved at a mineral-resource assessment work-

shop in Golden, Colo., in December 1979 (Shawe, 1981). The principal steps in the assessment (Pratt, 1981), as adapted to the Charlotte quadrangle area, are

1. Compilation of geologic, geochemical, and geophysical maps to identify the geologic environments of the area.
2. Determination of the types of known mineral deposits and of mineral commodities derived from these deposits and identification of commodities that are potentially derivable, as inferred from geochemical and heavy-mineral data obtained during this study.
3. Construction of descriptive models for the known mineral-deposit types by assembly of criteria that characterize the deposits.
4. Systematic correlation of geologic, mineral-occurrence, geochemical, mineralogic, and geophysical¹ data and comparison of the data with features of the descriptive models.

ESTIMATING MINERAL-RESOURCE POTENTIAL

Mineral resources of the Charlotte quadrangle are classified as identifiable (those that are known because of past or present production or adequate sampling) and having potential (those inferred to exist from less direct evidence and from diagnostic and permissive criteria described in the section "Criteria for assessment of mineral-resource potential"). This study is concerned mainly with identifying areas of mineral-resource potential; identified resources help in this process. Large areas of the quadrangle either are of unknown resource potential (unknown owing to a lack of significant or under-

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¹Geophysical data were not used directly in the Charlotte quadrangle but were indirectly important in aiding geologic interpretation of the area.

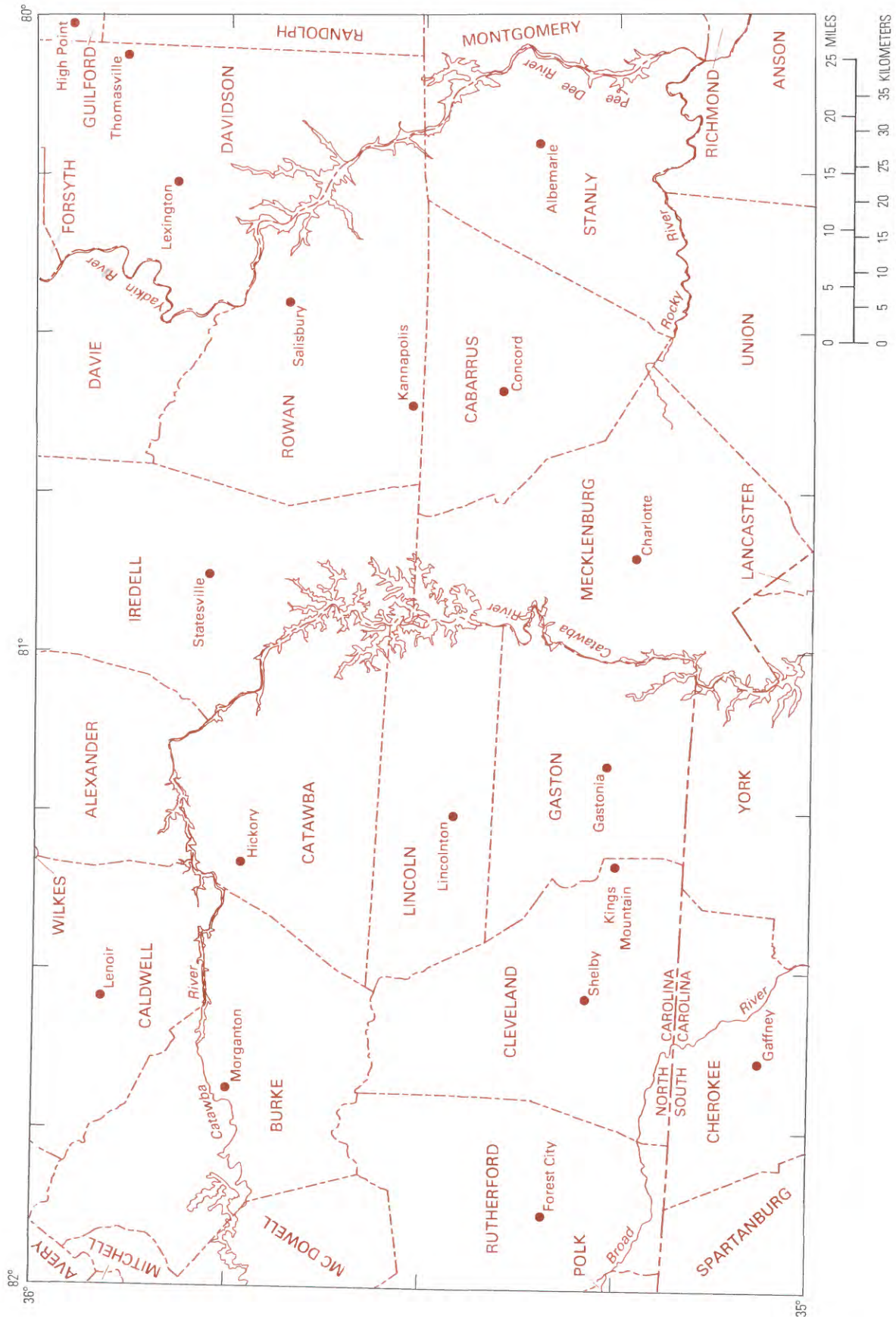


FIGURE 1.—Index map of the Charlotte quadrangle, showing principal population centers and drainages.

standable data) or are unfavorable for a given type of mineral deposit because of unfavorable evidence. Such areas generally occupy large parts of the quadrangle between smaller areas where there are favorable indications of mineral resources. The unknown or unfavorable areas thus are not readily delineated by local boundaries.

Inherent in the process of assessing mineral-resource potential is the determination of geographic distribution of favorable features and the estimation of mineral-resource potential by comparisons of favorable criteria and past production data.

Mineral production from an area ultimately depends on a host of factors; the most important is the presence of significant amounts of the mineral commodity at minable grade. Other critical factors are the costs of development and mining, price and marketability of the commodity, and technological factors affecting the processing and utilization of the commodity; all factors determine the economic viability of a given mineral occurrence and its potential value as a mineral resource. Many of these factors are subject to gradual or sporadic change and cannot be predicted far into the future. The estimates of mineral-resource potential in this report focus on geologic and other features of mineral occurrence that affect grades and volumes (tonnages) and have resulted in viable mining operations in the past. Estimates of resource potential are tempered by the assumption that lower grades of mineralized rock will become minable in the future, particularly if accompanied by increased tonnages.

THE CHARLOTTE QUADRANGLE, A MICROCOSM OF MINERALIZATION IN A LARGE PART OF THE SOUTHEASTERN UNITED STATES

The Charlotte quadrangle was selected for study because of its variety of mineral occurrences distributed in several geologic provinces (lithotectonic belts) including the Blue Ridge, Inner Piedmont, Kings Mountain, Charlotte, and Carolina slate belts and the Wadesboro basin of Triassic sedimentary rocks (also see section "Geology of the Charlotte 1°×2° quadrangle" by Goldsmith and others). The area is or has been a major producer of gold, lithium, and kyanite and an important producer of barite. In addition, it has produced small amounts of base metal (copper, lead, zinc). The Charlotte quadrangle can therefore be considered a virtual microcosm of mineralization in a large part of the Southeastern United States, the Piedmont in particular. As the first 1°×2° quadrangle in this region to be studied under CUSMAP, it offers a unique opportunity to test and refine techniques of assessing mineral-resource potential in this part of the United States.

CHARLOTTE CUSMAP PRODUCTS

Several maps and reports from the Charlotte CUSMAP study are available. They include three geophysical maps (Daniels and Zietz, 1981a,b; Wilson and Daniels, 1980), a report on cassiterite occurrences (D'Agostino and Whitlow, 1985), maps showing geochemical data (Duttweiler and others, 1985²; Griffiths and Hoffman, 1985; Griffiths and others, 1985²; Siems and others, 1985; Whitlow and others, 1985), a map showing mineral occurrences in relation to geology (D'Agostino and Rowe, 1986), and mineral-resource potential maps (Gair, 1986a,b,c; Gair and D'Agostino, 1986; Gair and Griffiths, 1986; Horton, 1987). A generalized version of the geologic map by Goldsmith and others (1988) is included in this report as plate 1.

The geologic mapping (Goldsmith and others, 1988; pl. 1) utilized older mapping, particularly from parts of the Blue Ridge and Inner Piedmont lithotectonic belts in the western half of the quadrangle and from the Carolina slate belt and the Wadesboro Triassic basin in the east, and some new mapping in those areas. Much of the mapping in the Kings Mountain and Charlotte belts is new (see geologic map by Goldsmith and others, 1988, for details and credits).

The simple Bouguer gravity anomaly map (Wilson and Daniels, 1980) combines 1,711 previous measurements and 1,286 readings taken at new stations. The aeromagnetic map contains data from seven separate surveys. Both black-and-white and colored versions of the aeromagnetic map have been published (Daniels and Zietz, 1981a,b). Long-wavelength anomalies show up better in the colored version, whereas short-wavelength anomalies and areas of high gradient show up better on the black-and-white version (Daniels and Zietz, 1981a,b; Gair and others, 1986). The aeroradioactivity map also was assembled from seven separate airborne total-count gamma-ray surveys. The map is a mosaic of the individual surveys because calibration and equipment specifications differed from survey to survey and precluded the surveys being joined together directly (Gair and others, 1986).

The map of the distribution of mineral deposits and prospects (D'Agostino and Rowe, 1986) was derived directly from data in the Mineral Resources Data System (MRDS) (formerly Computerized Resources Information Bank (CRIB)) of the U.S. Geological Survey, from data obtained from the literature, and from field location checks of hundreds of mineral occurrences.

The geochemical and heavy-mineral maps contain data from approximately 2,500 pan concentrates of stream

²"Duttweiler and others" and "Griffiths and others" include, for different maps, various combinations of Duttweiler, Griffiths, Whitlow, Botinelly, Hoffman, Siems, and Wilch.

sediment samples collected under CUSMAP, from trace-element data, from fine-grained (minus 100 mesh) samples of alluvium collected under the program for National Uranium Resource Evaluation (NURE) of the U.S. Department of Energy (Heffner and Ferguson, 1978), and from about 100 samples from previous heavy-mineral studies of the U.S. Geological Survey.

MINERAL-DEPOSIT TYPES (MODELS) IN THIS REPORT

The following mineral-deposit types (models) have been identified in the Charlotte quadrangle and are discussed in separate sections of this report. They are grouped whenever possible by their important mineral products, without regard to the relative order of productivity from the different types of deposits.

1. Polymetallic base-metal, precious-metal, and pyritic stratabound deposits in volcanic-sedimentary host rocks of the Carolina slate belt. Past or potential mineral products include copper, lead, zinc, gold, silver, and secondary (gossan) iron.

2. Gold-pyrite-quartz veins. Past, present, or potential products include gold, sulfur (from pyrite), and pure quartz (silica).

3. Placer deposits. Past, present, or potential mineral products include gold, tin, thorium (monazite), rare earths, and zirconium.

4. Saprolite deposits. Past, present, or potential mineral products include gold, mica, and clay.

5. Colluvial deposits. Potential mineral products include gold, zirconium, thorium (monazite), and niobium (columbite).

6. Gold in fossil placers in the Triassic sedimentary rocks of the Wadesboro basin.

7. Feldspar and mica pegmatites.

8. Spodumene in lithium-rich pegmatite of Mississippian age in the Inner Piedmont belt.

9. Cassiterite in tin-bearing pegmatites and greisens of the Inner Piedmont belt.

10. Kyanite and sillimanite in high-alumina quartzite of probable Late Proterozoic age in the Kings Mountain belt.

11. Sillimanite in schist of the Inner Piedmont belt.

12. Barite in quartz-sericite schist of probable Late Proterozoic age in the Kings Mountain belt.

13. Manganese oxides derived from weathering of stratabound spessartine-almandine garnet in schist of the Kings Mountain belt.

14. Iron (magnetite and hematite) in stratabound layers in metasedimentary schist and quartzite of probable Late Proterozoic age.

15. Iron (magnetite) associated with felsic and mafic gneisses.

16. Corundum associated with amphibole-rich rocks.

TABLE 1.—*Format for mineral deposit models*

Size and grade of deposits
Length
Width (or thickness)
Depth
Volume (tonnage)
Grade
Lithology of host rocks
Types of association with host rocks (mode of occurrence)
Controlling structure and relation to nearby rock bodies
Mineralogy of "ore"
Major
Minor
(or primary vs. secondary; metallic vs. gangue)
Geochemical and mineral indicators
Geophysical indicators

17. Uranium in veins, fracture fillings, and shears in granites and gneisses.

18. Construction materials (crushed stone, sand and gravel, clay, dimension stone, and flagstone). Note: this category is not a single deposit type but encompasses a variety of types; secondary factors, such as weathering and erosion, may have at least as much significance in forming the commodity as the nature of the original material.

These deposit types are presented in descriptive models. The models are constructed in accordance with a consistent format (table 1), which is designed to cover the significant descriptive deposit characteristics. The models therefore provide criteria for recognizing favorable conditions for the existence of deposits. An absence of data of the kind specified in a model generally will prevent a determination of the resource potential for that type of deposit. Data that contradict the principal features of a model may indicate that there are no potential resources of that deposit type.

Geochemical and (or) heavy-mineral data suggest a low potential for molybdenum and tungsten in some places in the quadrangle (Gair, 1986a,c) even though these commodities have not been produced or generally recognized as distinct deposit types in the area. Therefore, tungsten and molybdenum are discussed in resource-potential maps for the quadrangle, but no deposit models are presented for these commodities.

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GEOLOGY OF THE CHARLOTTE 1°×2° QUADRANGLE

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INTRODUCTION

The Charlotte 1°×2° quadrangle encompasses a transect across six lithotectonic belts of the Piedmont (fig. 2) from the Wadesboro Triassic basin on the east to the Blue Ridge in the vicinity of the Grandfather Mountain window on the west. Because these belts differ in geologic character, the geology of each is described separately. A generalized geologic map of the Charlotte quadrangle derived from a map by Goldsmith and others (1988) is included here (pl. 1). This generalized map is used as a base for maps evaluating mineral resources in the Charlotte quadrangle.

WADESBORO BASIN

The southeast corner of the Charlotte quadrangle lies within the Wadesboro basin, which is filled with Upper Triassic continental sedimentary rocks (fanglomerates, conglomerates, arkosic sandstones, and siltstones). Beds dip gently toward a major normal fault on the southeast margin of the basin. The northwest margin, within the Charlotte quadrangle, is marked by a series of minor faults bounding small sediment-filled troughs and graben. A basal conglomerate at the updip northwest margin of the basin contains debris from a granite pluton cut by the southeast marginal fault. This relation indicates that faulting and tilting were at least partly postdepositional. Poorly consolidated sands of the Upper Cretaceous Middendorf(?) Formation (outliers of the Coastal Plain) unconformably overlie Triassic strata of the Wadesboro basin. Another Triassic basin, the Davie County basin, barely extends into the quadrangle across its northern boundary.

Diabase dikes of Triassic and Jurassic age, generally with north-northwesterly trends, occur throughout the quadrangle but are particularly abundant in the Wadesboro basin and the nearby Carolina slate belt. Another swarm crosses the Charlotte and Kings Mountain belts between Charlotte, N.C., and Gaffney, S.C., and extends into the Inner Piedmont in Cleveland, Gaston, and Lincoln Counties. One of these dikes crosses the Brevard fault zone into the Blue Ridge.

CAROLINA SLATE BELT

The Carolina slate belt consists of weakly metamorphosed sedimentary and volcanic rocks. The lowest stratigraphic unit, the Uwharrie Formation, of which only the upper part crops out near the eastern edge of the quadrangle, is composed primarily of rhyolitic volcanic rocks. The overlying Albemarle Group is a dominantly clastic sedimentary sequence 5 or 6 km thick (Stromquist and Sundelius, 1969; Milton and Reinhardt, 1984). The grain sizes of this sequence show a general increase upward from the argillite of the Tillery Formation at the base, through the mudstone and siltstone of the Cid Formation and the siltstone of the Floyd Church Formation, to the graywacke of the Yadkin Formation at the top. A quarter to third of the volume of the Albemarle Group consists of volcanic rocks (mostly epiclastic), which, like the metavolcanic rocks of the Uwharrie Formation, compose a chemically bimodal calc-alkaline suite, with basaltic and rhyolitic compositions predominating over intermediate compositions (Seiders, 1978). Volcanic centers in the Albemarle Group, at High Rock (Flat Swamp) Mountain west of Denton, in the Mount Morrow-Badin area, and elsewhere are thick piles of tuffs, agglomerates, and hypabyssal intrusives that grade distally to thinner and finer grained tuff beds. The Flat Swamp Member of the Cid Formation makes a conspicuous marker bed that can be traced for 150 km. The Carolina slate belt may represent an island-arc environment in which slow, deep-water deposition of sediments, largely of distant volcanic derivation (although there is evidence of some material of continental provenance, Milton and Reinhardt, 1980), was locally and intermittently interrupted by massive deposition of volcanic material from nearby volcanoes.

Recent finds (Gibson and others, 1984) in the Floyd Church Formation of *Pteridinium* (or a closely related form), a metazoan fossil diagnostic of the Ediacarian or Vendian fauna of latest Precambrian age, and reinterpretation as *Pteridinium* of fossils earlier identified as Cambrian *Paradoxides* (St. Jean, 1973) indicate a Late Proterozoic age for the Albemarle Group. This dating is supported by a U-Pb date of 568 ± 10 Ma for zircon from

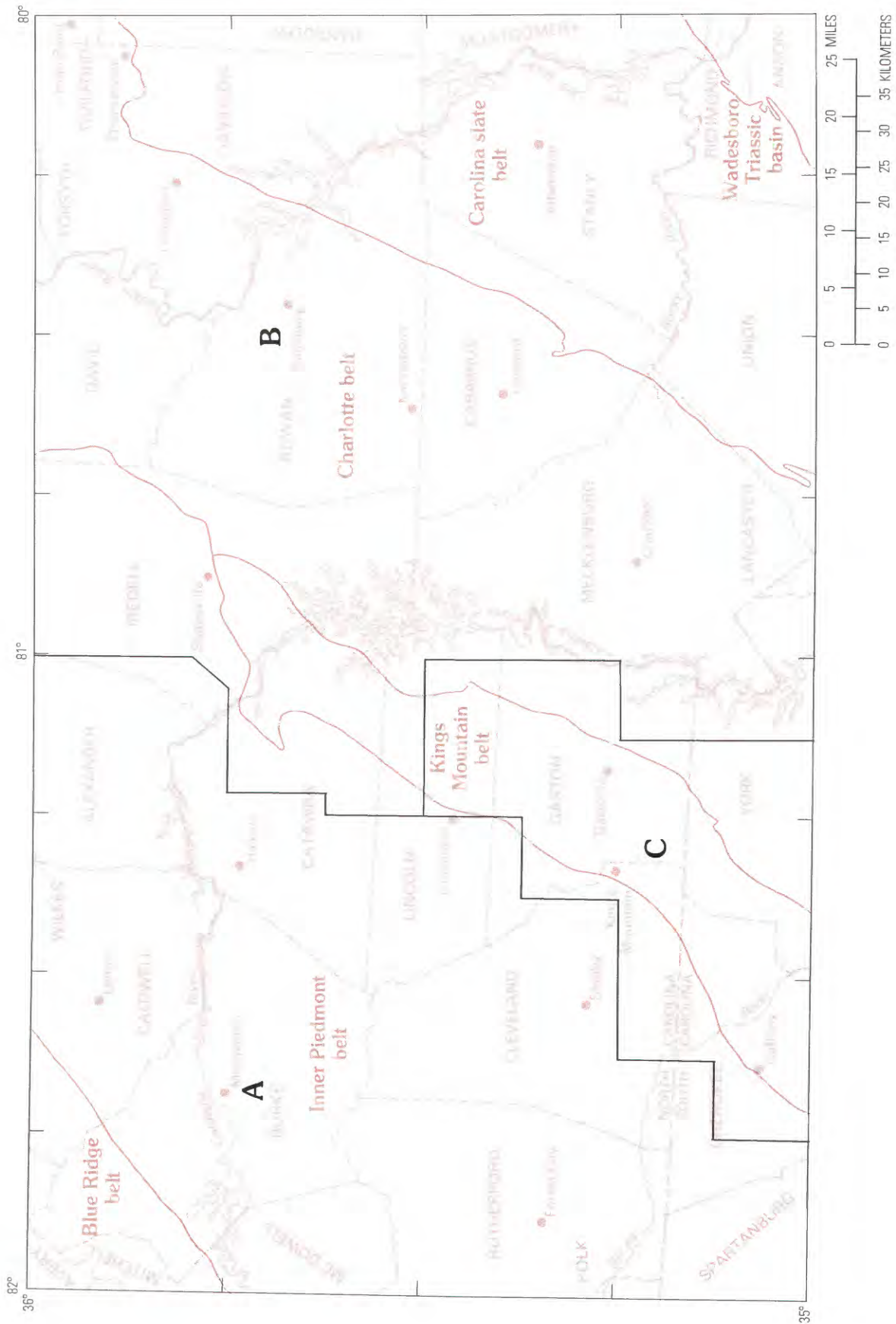


FIGURE 2. — Lithotectonic belts of the Charlotte quadrangle and areas of mapping responsibility. A, Richard Goldsmith; B, Daniel J. Milton; C, J. Wright Horton, Jr.

the uppermost Uwharrie Formation (Wright and Seiders, 1980).

Most of the rocks in the slate belt in the Charlotte quadrangle are in open folds about northeast-southwest-trending axes, forming two major anticlines, two major synclines, and many smaller folds. Beds dip gently to moderately, less commonly steeply, and are rarely overturned. Widely spaced axial plane cleavage generally is present. In contrast, a zone 3 to 5 km wide on the west edge of the slate belt (the Gold Hill shear zone) consists largely of phyllite having a vertical or steeply west-northwest-dipping cleavage. The phyllite and tuffaceous interbeds within it are probably strongly sheared and recrystallized beds of the Tillery or Cid Formations. Earlier detailed maps (Stromquist and others, 1971; Stromquist and Sundelius, 1975; Sundelius and Stromquist, 1978) portray the shear zone as bounded by the Silver Hill fault on the east and the Gold Hill fault on the west. Some units (notably the Flat Swamp Member) are truncated abruptly along the Silver Hill line, indication that it is indeed a fault. Nevertheless, the Denton anticline extends across the Silver Hill fault and changes from a gently plunging fold on the east to a steeply plunging fold in the shear zone; thus, any major displacement on the Silver Hill fault must antedate the folding. There is some evidence that the fault itself is folded by the Denton anticline, suggesting that shearing in the Gold Hill shear zone and folding to the east were roughly contemporaneous. No brecciation or other evidence of brittle deformation has been observed anywhere in the Gold Hill zone. The Gold Hill line is, in general, a contact between metasedimentary rocks on the east and metavolcanic rocks on the west, with no apparent angular discordance. In contrast to the Silver Hill line, it appears to be a stratigraphic contact, perhaps an unconformity, with the sequence on the east side presumably younger. The cumulative effect of shearing and unmapped small-scale faulting within the shear zone may have significantly reduced the original stratigraphic thickness of the sequence.

CHARLOTTE BELT

The Charlotte belt, to the west of the slate belt, is dominated by plutonic rocks, and some large areas of metavolcanic rocks but very few metasedimentary rocks. Varying degrees of development of metamorphic fabric and reconstitution of mineral assemblages indicate a range of ages for the igneous rocks that may be divided into pre-, syn-, and posttectonic-metamorphic suites, although assignments of many plutons are uncertain. The pre-tectonic suite, a metamorphosed volcanic-plutonic complex that forms the major part of the Charlotte belt, ranges in composition from ultramafic to felsic and from

coarse-grained plutonic rocks to porphyritic hypabyssal rocks to extrusive volcanic flows and tuffs. The Charlotte belt may represent the axial part of an island arc eroded to a deep level, whereas the Uwharrie Formation and the Albemarle Group of the slate belt form an off-axis facies that is shallower and richer in sediment. Alternatively, the Charlotte belt metavolcanic rocks (and older meta-plutonic rocks) may correlate with the 600- to 700-Ma series of volcanic rocks of the Carolina slate belt exposed in the Roxboro-Durham area (Glover and Sinha, 1973; Seiders and Wright, 1977). Radiometric dating of the pre-tectonic Charlotte belt rocks has been attempted only on metagranodiorite from York County, S.C., from which zircons yielded a U-Pb concordia age of 532 ± 15 Ma (Law Engineering Testing Co., 1976). The metamafic complex of the eastern and northern parts of the Charlotte belt may include ophiolitic associations. The syn-tectonic Salisbury Plutonic Suite is composed of leucocratic nonporphyritic granites that are generally weakly foliated and recrystallized. These have been dated at around 400 Ma (Butler and Fullagar, 1978). The gabbroic rocks present particularly complex problems in age assignment because gabbros commonly intrude older metagabbros (McSween, 1981). Gabbros and associated syenites of the Concord Plutonic Suite have been dated at about 405 Ma by Rb/Sr (Fullagar, 1971), Nd/Sm (Olsen and others, 1983), and $^{40}\text{Ar}/^{39}\text{Ar}$ (Sutter and others, 1983) methods. The youngest major intrusive bodies of the Charlotte belt are the large post-tectonic porphyritic granites of the Churchland Plutonic Suite that have been dated at between 280 and 320 Ma (Fullagar and Butler, 1979; Speer and others, 1979).

The paucity of metasedimentary or stratified rocks makes the structural and metamorphic patterns of the Charlotte belt obscure. Trends of rock units, foliation, and magnetic anomalies in the northern and eastern parts of the belt have the common Appalachian northeast-southwest orientation in the northern half of the quadrangle but curve to east-west near Charlotte and even farther to northwest-southeast near Lake Norman in the western part of the belt. This curvature suggests a large fold open to the northeast that involves most of the Charlotte belt within the quadrangle. Regional metamorphism reaches amphibolite grade and appears to be of lower grade on either flank than in the center of the belt. Metamorphic aureoles of hornfels facies enclose some intrusives. Hornblends from amphibolite give $^{40}\text{Ar}/^{39}\text{Ar}$ plateau ages of 425 to 430 Ma; these ages indicate a Taconic age for regional metamorphism (Sutter and others, 1983).

The boundary between the Charlotte belt and the Inner Piedmont, in the north-central part of the quadrangle, unlike the Gold Hill zone, is marked by brecciation and cataclasis, apparently superimposed on earlier

mylonitized rocks. This zone, which we have named the Eufola fault (Milton, 1981), is continuous with the boundary faults of the Davie County basin, thereby indicating that some movement occurred at least as late as Triassic. The character of displacement on the Eufola fault is unknown. The broad curve of the fault trace from north-south to east-west constrains interpretations of its configuration. The Charlotte and Kings Mountain belts may have been thrust northward over the Inner Piedmont in the southern segment of the Eufola fault, implying right-lateral strike-slip movement in the northern segment.

KINGS MOUNTAIN BELT

The Kings Mountain belt is characterized by distinctive metasedimentary and metavolcanic rocks, steep dips, and metamorphic grades that are commonly lower than in nearby parts of adjacent belts. The attitudes of beds and metamorphic grades, however, vary from place to place within and across the lithostratigraphic units (Horton, 1981b).

Lithostratigraphic units of the Kings Mountain belt are divided into the Blacksburg Formation, which lies west of the Kings Creek and Blacksburg shear zones, and the Battleground Formation, which lies east of these shear zones. Both are inferred to be of Late Proterozoic age (Horton, 1981b). The lower part of the Battleground Formation consists mostly of metavolcanic rocks interlayered with quartz-sericite schist. Metavolcanic facies include fine-grained hornblende gneiss, fine-grained feldspathic biotite gneiss, and phyllitic or schistose metavolcaniclastic rocks. These rocks grade laterally and vertically into quartz-sericite schist. The high quartz content and lack of volcanic textures and mineralogy, except for minor plagioclase in the quartz-sericite schist, suggest that it originated from epiclastic or sedimentary materials and possibly (at least in part) from hydrothermally altered volcanic materials that may or may not have been reworked by sedimentary processes. The upper part of the Battleground Formation consists of quartz-sericite schist interbedded with high-alumina (kyanite or sillimanite) quartzite, quartz-pebble metaconglomerate, spessartine-quartz rock, and quartzite.

The Blacksburg Formation consists of sericite schist or phyllite having beds or lenses of marble and calc-silicate rock, micaceous quartzite, and amphibolite. The sericite schist is commonly graphitic and contains more white mica but less quartz and plagioclase than quartz-sericite schist of the Battleground Formation. The Blacksburg Formation is predominantly sedimentary in origin, but the amphibolite lenses have basaltic compositions and may be metamorphosed sills or flows. The stratigraphic

relationship between the Blacksburg and Battleground Formations is uncertain because of intervening faults and plutons.

Metatonalite and metatrandjemite intrusions of Late Proterozoic(?) age are present in the Kings Mountain belt and are most abundant in the stratigraphically lower part of the Battleground Formation. The metatonalite bodies may represent shallow sills and plugs that intruded their own volcanic ejecta (Horton, 1977; Murphy and Butler, 1981). They are similar to metatonalite along the western side of the Charlotte belt. The Kings Mountain belt also contains bodies of metagabbro and metadiorite like those of the Charlotte belt. Metagabbro dikes cut the metatonalite in places. Lenticular bodies of ultramafic rock, including metapyroxenite and soapstone, occur on the western side of the Kings Mountain belt just southwest of Gaffney, S.C. The High Shoals Granite, a coarse-grained, porphyritic, gneissoid biotite granite or granitic gneiss, occupies an area of batholithic size within the Kings Mountain belt. U-Pb data from zircons indicate a Pennsylvanian age of about 317 Ma for this intrusion (Horton and Stern, 1983). The undeformed porphyritic biotite granite at Gastonia, N.C., part of the batholith that includes the High Shoals Granite, resembles other Pennsylvanian-Permian plutons of the Churchland Plutonic Suite in composition and texture.

As many as five episodes of folding and related deformation have been recognized in the Kings Mountain belt (Horton, 1981b). The pattern of rock units on the map is controlled largely by folds of the two earliest episodes, F_1 and F_2 . These folds are locally disrupted by tectonic slides or ductile faults that are roughly parallel to the regional schistosity (Butler, 1981; Horton, 1981b). The largest map-scale folds are the South Fork antiform and Cherokee Falls synform, which are interpreted as F_2 structures (Horton, 1981b). Structures younger than F_2 are conspicuous in the major shear zones but are sporadically distributed elsewhere and rarely affect the map pattern.

Ductile shear zones occur along both margins of the Kings Mountain belt and within it. The most significant of these, the Kings Mountain shear zone, separates the Kings Mountain and Inner Piedmont belts. Rock units and metamorphic isograds on both sides of the zone are truncated against it (Horton, 1981a). The shear zone that marks the eastern boundary of the Kings Mountain belt near Gastonia, N.C., does not extend northward into Lincoln County. There are no lithostratigraphic criteria to distinguish rocks in the lower part of the Battleground Formation from similar, possibly correlative metavolcanic and metasedimentary rocks in the Charlotte belt. In Lincoln County, the boundary between the Kings Mountain and Charlotte belts is defined partly by intrusive

contacts, and some rock units have been assigned arbitrarily to one belt or the other.

Metamorphic grade within the Kings Mountain belt ranges from greenschist to amphibolite facies. The areas of greenschist facies or epidote-amphibolite facies metamorphism are lower in grade than nearby parts of the adjacent belts. A well-defined zone of Alleghanian-age sillimanite-grade metamorphism surrounds the High Shoals Granite. Regional metamorphism of this age, which overprints an older but lower grade Paleozoic metamorphic event, extends beyond the immediate vicinity of the granite (Horton and Stern, 1983; Sutter and others, 1984).

Similarities among the Kings Mountain belt, Charlotte belt, and Carolina slate belt suggest that they are parts of a single terrane, perhaps a Late Proterozoic volcanic arc-basin complex. If so, the Charlotte belt may represent a deeply eroded zone in which more plutonic rocks are exposed than in the Kings Mountain and Carolina slate belts.

INNER PIEDMONT BELT

The Inner Piedmont belt lies between the Charlotte and Kings Mountain belts to the east and the Blue Ridge to the west. It is separated from the Charlotte and Kings Mountain belts by the Kings Mountain and Eufola fault zones and from the Blue Ridge by the Brevard fault zone.

Stratified rocks of the Inner Piedmont consist predominantly of thinly layered mica schist and biotite gneiss interlayered with lesser amounts of amphibolite, calc-silicate rock, hornblende gneiss, quartzite, and some rare marble. Protoliths of these rocks were largely sedimentary, in part volcanic. Much of the biotite gneiss was probably a graywacke, but some layers could have been intermediate volcanic flows or tuffs. Some of the mica schist is feldspathic and may have had a tuffaceous component. A thin gondite or quartzite rich in manganese garnet was probably a manganiferous chert.

Two stratigraphic suites seem to be present. A mostly mafic, (structurally) lower suite consists mainly of biotite gneiss and amphibolite and layers of mica schist and layered granitoid gneiss that may be felsic metavolcanic material. This suite structurally underlies an upper suite consisting of interlayered mica schist, biotite paragneiss, and minor calc-silicate rock. Distinctive strata mark the top of the lower suite and bottom of the upper suite. Near the top of the lower suite is a lenticular rock resembling a diamictite that lies physically below amphibolite. Overlying the amphibolite is a locally conglomeratic quartzite and quartz schist or, in places, a feldspathic mica schist that constitutes the base of the upper suite. The complexity of structure within the Inner Piedmont, the lack of recognizable indicators of

facing direction and of primary features except layering, and the paucity of distinctive marker units make recognition of a more detailed stratigraphic sequence uncertain. The upper suite occupies the high-grade central core of the Inner Piedmont, and the lower suite flanks the central core to the northwest and east. The upper suite is at medium metamorphic grade in a belt southeast of the Brevard zone and in a belt northwest of the Kings Mountain shear zone. Lenses of marble occur along the Brevard zone, and one outcrop of marble was observed on the southeastern flank of the Inner Piedmont in Cherokee County, S.C. The age of the stratified rocks in the Inner Piedmont is unknown; because they are intruded by granite that is probably as old as Cambrian, they are probably of Proterozoic age but no younger than Cambrian.

Many large and small masses of granite and granodiorite, and a few masses of quartz diorite, are scattered through the Inner Piedmont. The Toluca Granite, a gray, medium-grained biotite granite grading into granodiorite, is distributed widely in the central core of the Inner Piedmont. The Toluca forms concordant to semi-concordant masses, some of which are gneissic and appear to be older than a poorly foliated to nonfoliated facies. A porphyritic granite, informally called the granite of Sandy Mush (Goldsmith and others, 1988) and probably related to the Toluca, forms semiconcordant masses from Sandy Mush, Rutherford County, N.C., to Cowpens, Spartanburg County, S.C. Along the western flank of the Inner Piedmont are elongate masses of porphyritic granitoid Henderson Gneiss, probably extensions of larger masses in the type area to the southwest (Hadley and Nelson, 1971). Tabular masses of dark-colored, nonlayered, garnetiferous, porphyritic biotite gneiss, considered to be a phase of the Henderson, are aligned on both sides of the central core of the Inner Piedmont. An extensive mass of migmatitic gneissic granite that resembles the gneissic Toluca Granite occupies a zone west of the central core and east of the marginal belt containing the Henderson Gneiss. This migmatitic granite contains inclusions of biotite gneiss and amphibolite and masses of nongneissic granite similar to the nongneissic part of the Toluca. Similar migmatitic granite is exposed in the mafic suite on the northeast side of the central core, but most masses are small. The Henderson and the Toluca are considered to be of Cambrian age on the basis of somewhat ambiguous isotopic data (Davis and others, 1962; Odom and Fullagar, 1973; Odom and Russell, 1975; Kish, 1977), but ages as young as Ordovician have been determined by Harper and Fullagar (1981) from other Inner Piedmont granites that may be, at least in part, equivalent to the Toluca.

Late-metamorphic to postmetamorphic two-mica Cherryville Granite of Mississippian age (Kish, 1977)

intrudes mica schist and gneiss southeast of the central belt of Toluca Granite. Sills and dikes of two-mica granite elsewhere in the Inner Piedmont may be a late phase of the Toluca or they may be related to the Cherryville. A few gneissic and nongneissic masses of quartz diorite intrude the stratified rocks in the eastern and western side of the central core. Small, apparently rootless, ultramafic masses, most altered to soapstone or serpentinite, are scattered along the east and west sides of the Inner Piedmont. The largest of these are located along the northeast side of the Inner Piedmont within the lower suite in Iredell and Catawba Counties. A less altered ultramafic mass lies in the central core of the Inner Piedmont in Burke County, N.C.

Rocks of the central core of the Inner Piedmont are in the sillimanite-muscovite zone of regional Barrovian metamorphism. The flanks are mostly in the staurolite-kyanite zone. Both zones contain many areas where aluminosilicate minerals have been altered to sericite and locally to muscovite, which indicates a period of hydration following the main dynamothermal peak. Butler (1972) considered the main period of regional metamorphism in the Inner Piedmont of the Carolinas and Georgia to have been about 410 to 430 Ma; some evidence exists for an Acadian event (Hatcher and others, 1979). The complex deformational and intrusive history of the Inner Piedmont remains to be documented.

The Inner Piedmont is probably allochthonous, and the rocks are polydeformed (Cook, Albaugh, Brown, Kaufman, Oliver, and Hatcher, 1979; Cook, Albaugh, Brown, Oliver, Kaufman, and Hatcher, 1979; Harris and Bayer, 1979; Goldsmith, 1981). Their original position is unknown. Ductile and locally brittle faults flank the Inner Piedmont on its northwest and southeast sides. The structural style changes abruptly across the Kings Mountain shear zone from tightly appressed, steeply dipping folds in the Kings Mountain belt to flat dips and recumbent folding in the Inner Piedmont. Basement rocks of the Sauratown Mountains, 15 to 20 km north of the quadrangle boundary, plunge southward under the rocks of the Inner Piedmont beneath the Yadkin fault.

The Inner Piedmont has been extensively folded and faulted. An early-formed foliation is parallel to layering, except around vestigial early fold hinges. This foliation has been tightly to isoclinally folded about gently plunging axes and moderately inclined to recumbent axial surfaces (Goldsmith, 1981). Direction of transport is generally west to northwest. Sheared-off limbs of folds and anastomosing shear surfaces are common. Small granite dikes have been emplaced along shears, and the position of some larger granite masses in the central core appears to coincide with discordances (probably major shears) suggested by the map pattern of foliation. Later upright folds have refolded the earlier folds about gently

plunging subhorizontal axes and moderately to steeply dipping axial surfaces that strike east-northeast, northeast, and north. These folds have produced broad synforms and antiforms across the earlier structures.

The overall structural pattern of the Inner Piedmont is an asymmetric synform, although the high-grade metamorphic core suggests an anticlinal structure. Alternative explanations include a difference in metamorphic grade between flanks and core, inversion of a nappe, and stacking of thrust sheets (Goldsmith, 1981). Foliations and axial surfaces of the earlier folds dip moderately southeast near the Brevard zone but flatten toward the core of the Inner Piedmont and locally dip west. Moderate dips to the west prevail along the eastern side of the Inner Piedmont belt but steepen abruptly near the Kings Mountain belt. In the Gaffney area, however, the dip is east into the Kings Mountain fault. The overall map pattern suggests the presence of nappe structures such as those described by Griffin (1974) to the southwest of the quadrangle and those indicated by the map of the Shelby quadrangle (Overstreet and others, 1963). This interpretation is supported by gently dipping anastomosing faults and sheared-off recumbent folds seen in many outcrops. Specific boundaries for such nappes, if present, have not been identified in the Charlotte quadrangle.

If the Inner Piedmont is allochthonous, linear northeast-trending ridges and valleys and repetition of units in the Inner Piedmont near the Brevard zone suggest that unrecognized subsidiary thrusts and normal faults may be present in this part of the Inner Piedmont. Such faults are indicated by patterns in seismic profiles across the belt in the Winston-Salem 1°×2° quadrangle to the north (L.D. Harris, K.C. Bayer, and W. DeWitt, Jr., 1983, oral commun.). The Eufola fault (Milton, 1981), which bounds the Inner Piedmont on the east, projects into the Inner Piedmont and swings southward north of Lincolnton. Here it may connect with a fault that strikes into the western edge of the Cherryville Granite and coincides with the boundary between the sillimanite and kyanite metamorphic zones. However, no evidence for such faulting has been seen in the Cherryville. A few high-angle faults have been observed in outcrop and deduced from map patterns within the Inner Piedmont, particularly in the area of the South Mountains and Cherry Mountain. The South Mountains may be an uplifted block tilted toward the southeast. En echelon dike-like masses of silicified breccia trend north-northeasterly near Sunshine, Rutherford County, N.C., and may define a fault system of Mesozoic or younger age (Snipes and others, 1979). No offset can be discerned along the prominent lineament coinciding with the Catawba River in Caldwell, Burke, and Alexander Counties, N.C., although a minor fault was seen in one

outcrop. A fault of minor displacement was observed along the linear Henry Fork in Burke County.

BLUE RIDGE BELT

The oldest rock in the Blue Ridge belt in the Charlotte quadrangle is the Elk Park Plutonic Suite of Middle Proterozoic age (1 Ga) (Davis and others, 1962), which consists of the Cranberry Gneiss, a composite of massive stratiform granite; the Wilson Creek Gneiss, a granite to granodiorite gneiss containing enclaves of paragneiss and schist; and the Blowing Rock Gneiss, a gneissic porphyritic granite to granodiorite. The Late Proterozoic Grandfather Mountain Formation lies unconformably over the Wilson Creek Gneiss. This formation consists of weakly metamorphosed arkose, arkosic conglomerate, siltstone (now in part phyllitic), and felsic to mafic metavolcanic rocks. The Ashe Formation lies unconformably over the Cranberry Gneiss. It is inferred to be about the same age as the Grandfather Mountain Formation and consists of metawacke, pelitic schist and gneiss, and zones of amphibolite. The Alligator Back Formation appears to overlie the Ashe Formation conformably (Rankin and others, 1973, p. 17) and consists of thinly layered to laminated silicic schist and gneiss. The upper age limit of the Alligator Back is uncertain, but it could be as young as early Paleozoic (Espenshade and others, 1975). The youngest sedimentary rocks of known age in the Blue Ridge belt in the Charlotte quadrangle are the Late Proterozoic to Early Cambrian Chilhowee Group and the overlying Early Cambrian Shady Dolomite. The Chilhowee Group here consists of an upper and a lower quartzite and an intervening phyllite unit.

The Blue Ridge belt contains elements of two suites of intrusive rocks. The Brown Mountain Granite of the Crossnore Complex of Late Proterozoic age intrudes the Wilson Creek Gneiss, and the Spruce Pine Alaskite of Late Ordovician to Early Devonian age (Kish, 1976) intrudes the Ashe Formation in the Spruce Pine area in the extreme northwest corner of the quadrangle. A sliver of granite similar to the Spruce Pine Alaskite is located in the Brevard zone at the north edge of the quadrangle.

During the Paleozoic, metasedimentary and metavolcanic rocks within the Grandfather Mountain window underwent prograde metamorphism to the greenschist facies, Grenville-age rocks were retrograded, and the Ashe Formation and other rocks now outside the window were metamorphosed to amphibolite-facies assemblages. Rocks in and immediately west of the Brevard fault zone are variably sheared and blastomylonitic. Butler (1973) has postulated three phases of Paleozoic metamorphism and deformation in the Blue Ridge belt. The main

episode of regional metamorphism probably occurred during the early Paleozoic Taconic orogeny, about 450 Ma.

The Blue Ridge consists of a series of thrust sheets stacked above a sole thrust (Cook, Albaugh, Brown, Kaufman, Oliver, and Hatcher, 1979). The uppermost sheet in the Charlotte quadrangle and adjacent Winston-Salem quadrangle has been breached to produce the Grandfather Mountain window. Within the window, two lower thrust sheets are exposed. The lowest sheet contains the Wilson Creek Gneiss, Blowing Rock Gneiss, and the Grandfather Mountain Formation. The Table Mountain thrust sheet, in an intermediate position, contains rocks of the Chilhowee Group and the Shady Dolomite. The Cranberry Gneiss and Ashe Formation in the uppermost sheet form the bounding rocks of the window above the Linville Falls fault. Subsidiary faults are recognized in places.

The Brevard zone forms the boundary between the Blue Ridge and the Inner Piedmont in the Charlotte quadrangle. It is a zone of ductile faulting in which the fault surfaces dip moderately southeast (Bryant and Reed, 1970) but are inflected and probably flatten to the southeast (Cook, Albaugh, Brown, Oliver, Kaufman, and Hatcher, 1979). Horton (1979) has described brittle faulting in the Brevard zone southwest of the quadrangle. The Brevard is, partly, a splay off the southern Appalachian sole thrust (Harris and Bayer, 1979; Cook, Albaugh, Brown, Kaufman, Oliver, and Hatcher, 1979) and represents a higher level décollement surface beneath the Inner Piedmont rocks. The Brevard zone encompasses faults in and bounding the Sauratown Mountains window north of the quadrangle (Espenshade and others, 1975).

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GEOPHYSICAL SURVEYS

By DAVID L. DANIELS

INTRODUCTION

Incorporated into the design of the Conterminous United States Mineral Assessment Program (CUSMAP) is the early acquisition of regional geophysical data that may be used to aid geologic mapping. Separately these data may delineate totally concealed geologic features. Aeromagnetic mapping aided in the rapid identification of lithologies and structural trends and provided uniform regional coverage. Airborne gamma-ray mapping (total-count) was included with the aeromagnetic survey because radiometric data were considered to be geologically diagnostic in the Charlotte quadrangle and the terrain is amenable to low-level flight. A gravity survey was made to complement and increase the usefulness of the magnetic survey and to provide independent data on lithology and structure.

SOURCES OF DATA

Previous airborne surveys by the U.S. Geological Survey (USGS) and USGS-State cooperatives had covered about half of the quadrangle with good-quality airborne magnetic and total-count gamma-ray surveys at the inception of the program. The earliest airborne surveys (Bates and Bell, 1965; Stromquist and Sundelius, 1975), areas A and B of figure 3, were flown in 1956, at 0.5-mi flight-line spacing. The remaining surveys, including those funded by the program, were flown at 1-mi flight-line spacing between 1975 and 1978 in east-west flight lines at 500 ft above ground to accommodate the total-count gamma-ray measurements. The magnetic and gamma-ray data from the seven surveys (fig. 3) were compiled into single contour maps at a scale of 1:250,000 (Daniels and Zietz, 1981a,b, 1982). Figures 4A and 4B are reduced versions of the published magnetic and gamma-ray contour maps. The boundaries of the major lithotectonic belts within the quadrangle also are shown on figures 4A-C (Goldsmith and others, 1988). Figure 4B, showing total-count gamma-ray intensities in the Charlotte quadrangle, differs significantly from the published total-count map in that the contour

interval has been increased to 250 c/s (counts per second), the contours have been generalized and drawn across survey boundaries, and shading has been applied to all values greater than 750 c/s.

In addition to these data, a separate spectral gamma-ray survey of the quadrangle was flown in 1977 (LKB Resources, Inc., 1979) along east-west flight lines 500 ft above ground and spaced 3 mi apart (fig. 5). This survey was part of the U.S. Department of Energy National Uranium Resource Evaluation (NURE) program. The spectral data were not contoured because of wide flight-line spacing, but stacked profiles of the data are useful for calibration and for identification of the principal component of each of the total-count anomalies. Significant advantages accrue from a spectral survey versus a total-count survey. In a spectral survey, the signal is differentiated electronically into three energy bands selected to correspond to the gamma radiation from potassium-40 (present in all natural potassium), bismuth-214 (a disintegration product of uranium through a number of intermediate isotopes), and thallium-208 (a disintegration product of thorium).

A supplemental gravity survey of the quadrangle for the CUSMAP program was begun by Frederick Wilson of the USGS in 1977. Nearly 1,300 new measurements were added to 1,700 measurements made by others (Snyder, 1963; Morgan and Mann, 1964; Watkins and Yuval, 1966; Best and others, 1973) during the previous 20 years. The new measurements were spaced 1 to 2 mi apart in areas of previously sparse data in the Charlotte belt and parts of the Kings Mountain and Carolina slate belts, mainly in the areas where the most significant density contrasts between felsic and mafic plutonic rocks were known to occur. Reconnaissance gravity profiles, spaced about 10 to 15 mi apart and consisting of measurements every mile, traversed the Inner Piedmont and Blue Ridge, where density contrasts are minimal. The new data were combined with the previous data in a simple Bouguer gravity anomaly map having a contour interval of 2 mGal (Wilson and Daniels, 1980); figure 4C is a reduced version of the gravity map.

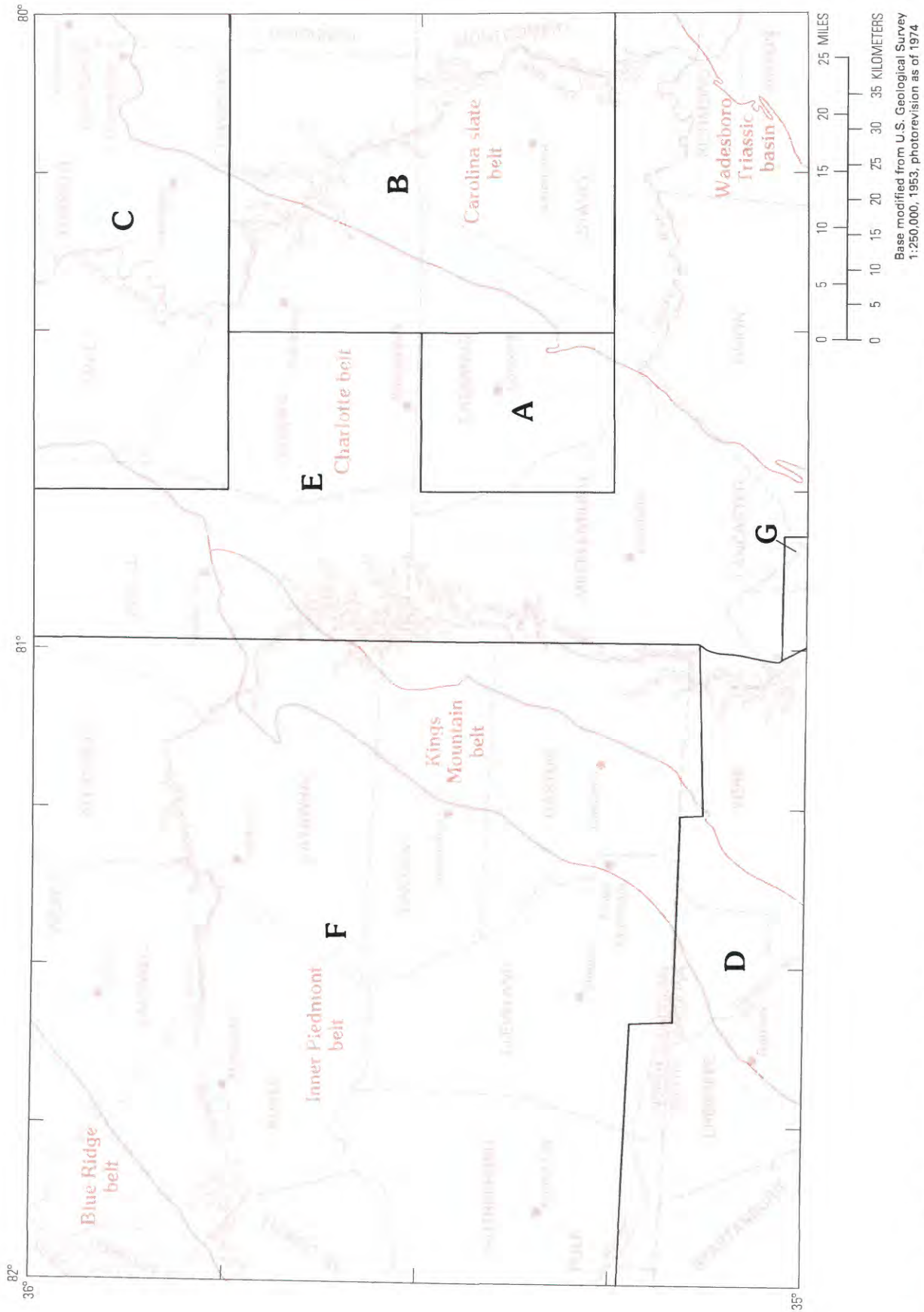


FIGURE 3. — Index map showing coverage of airborne magnetic and total-count gamma-ray surveys of the Charlotte quadrangle. All flights were east-west and 500 ft (152 m) above the ground. A–G indicate survey areas. A and B were flown in 1956 at 0.5-mi flight-line spacing. C–G were flown between 1975 and 1978 in east-west flight lines at 1-mi flight-line spacing.

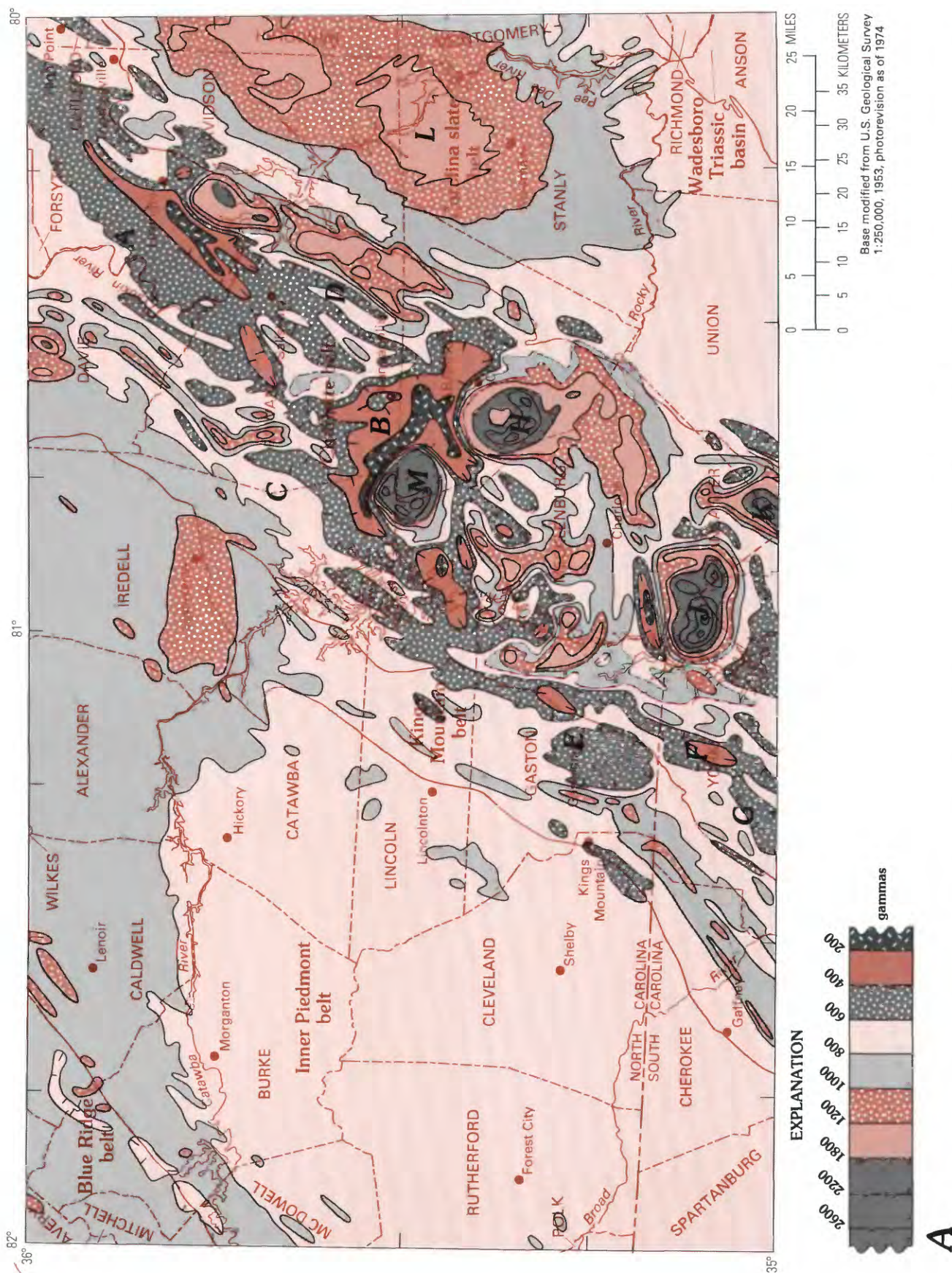


FIGURE 4.—Geophysical maps of the Charlotte quadrangle. A, Generalized residual aeromagnetic map (from Daniels and Zietz, 1981a,b). Letters refer to gravity anomalies explained in text.

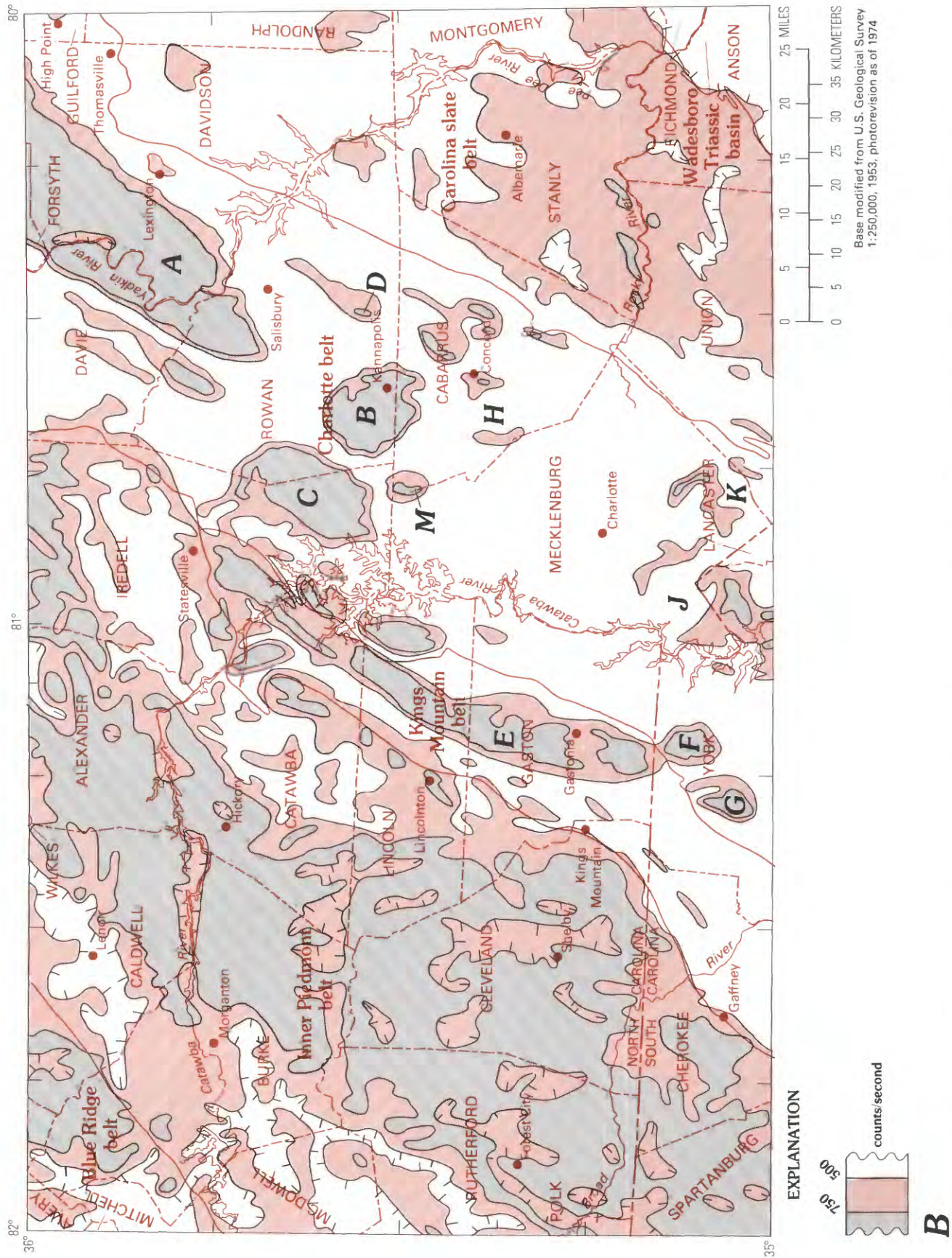


FIGURE 4.—Continued. B) Generalized total-count gamma-ray map (from Daniels and Zietz, 1982). Letters refer to gravity anomalies explained in text.

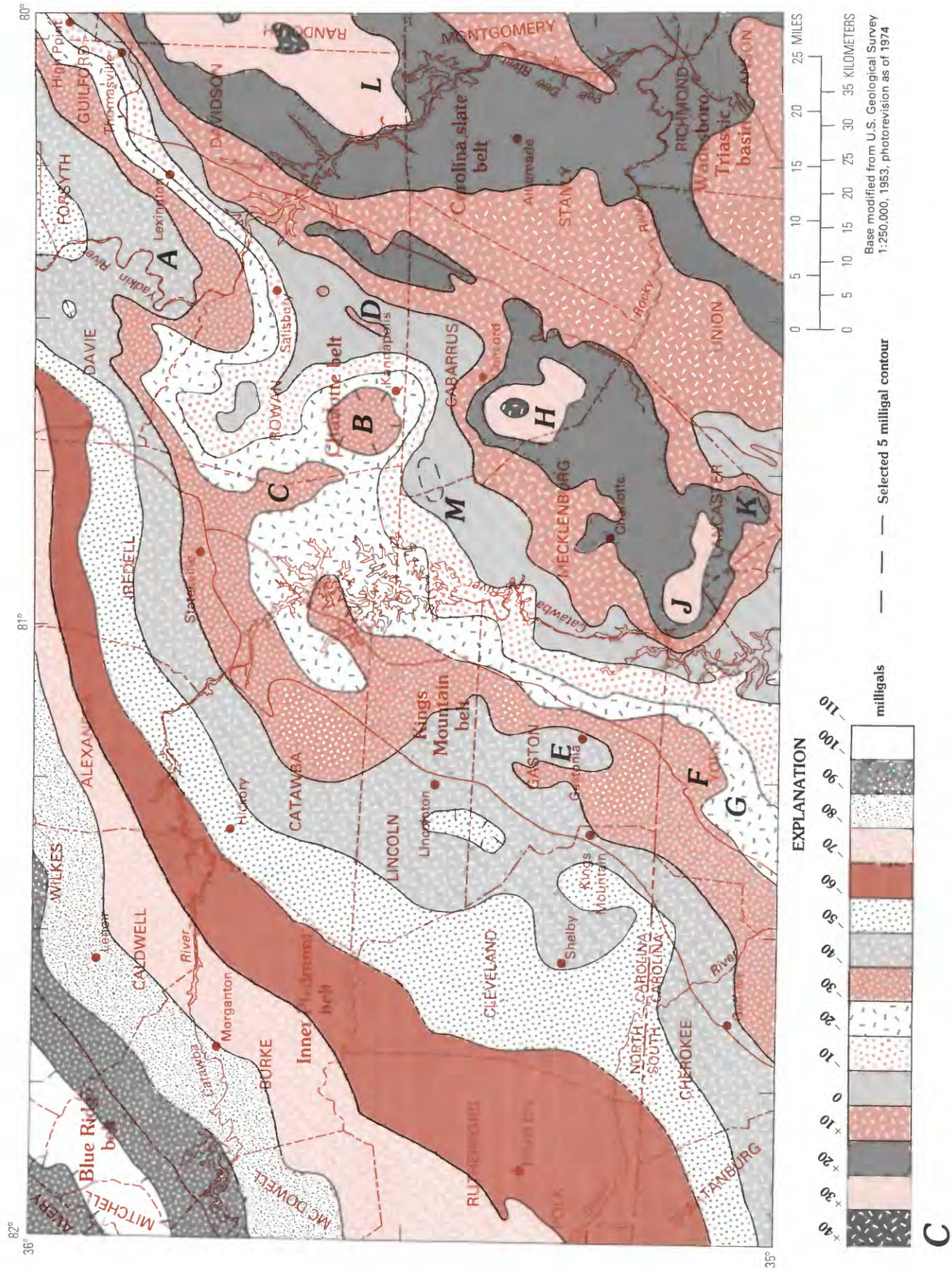


FIGURE 4. — Continued. C, Simple Bouguer gravity anomaly map having 10-mGal contour interval and dashed 5-mGal contours (from Wilson and Daniels, 1980). Letters refer to gravity anomalies explained in text.

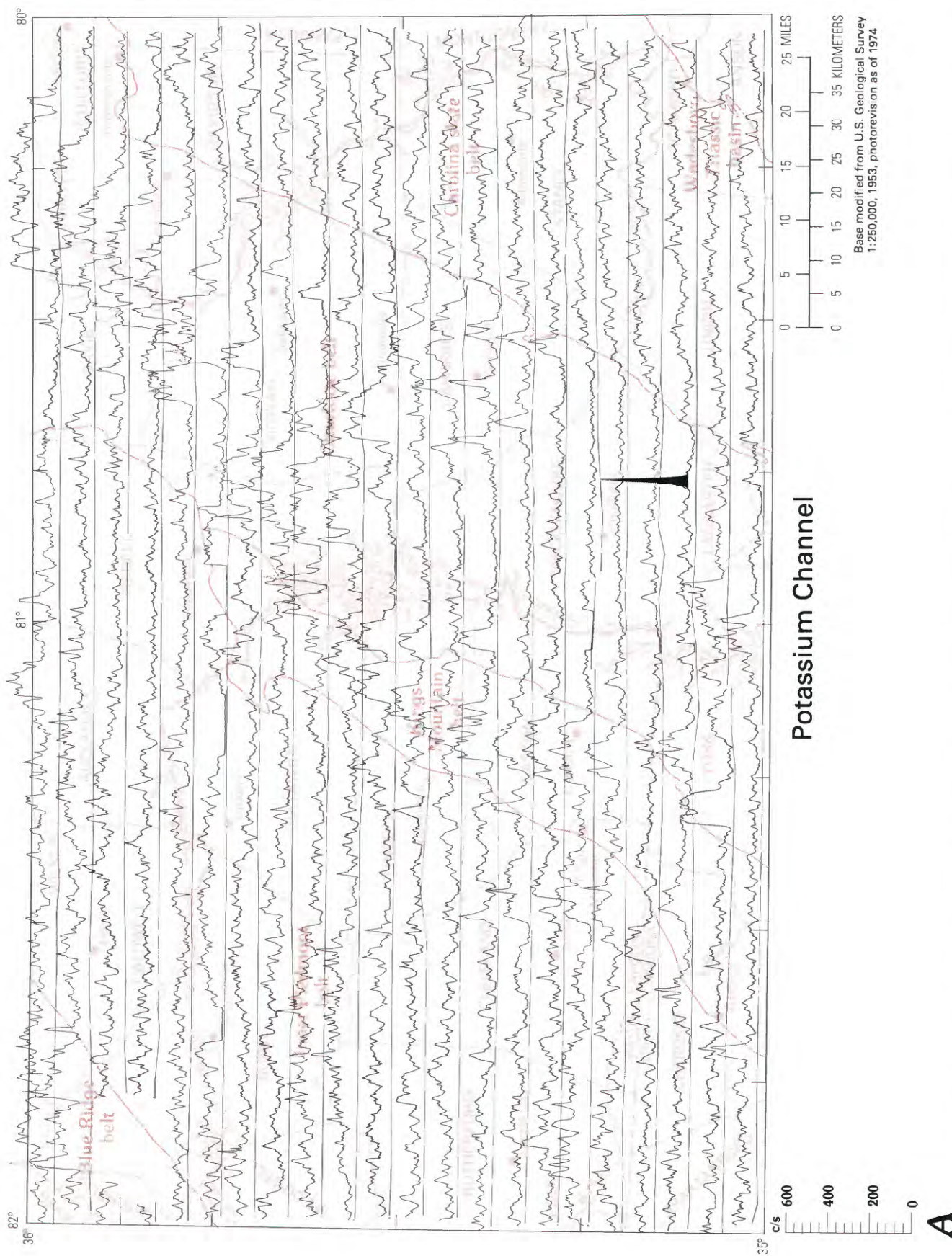


Figure 5. — Stacked profiles of airborne spectral gamma-ray measurements of the Charlotte quadrangle. A, Potassium-40 (potassium) channel. Bar scale at the left of figure shows vertical scale of channel in counts per second (c/s).

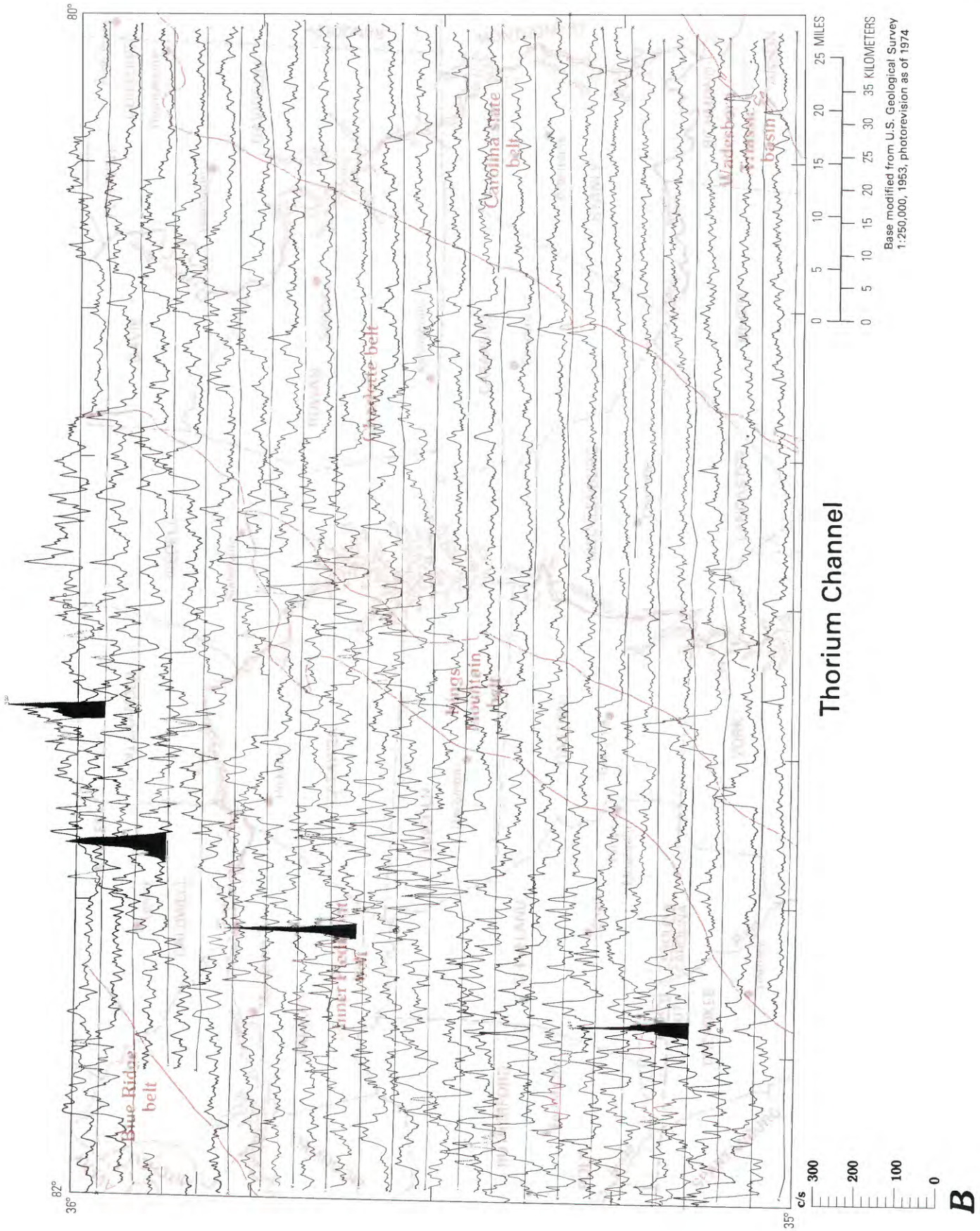


FIGURE 5. — Continued. B, Thallium-208 (thorium) channel. Bar scale at the left of figure shows vertical scale of channel in counts per second (c/s).

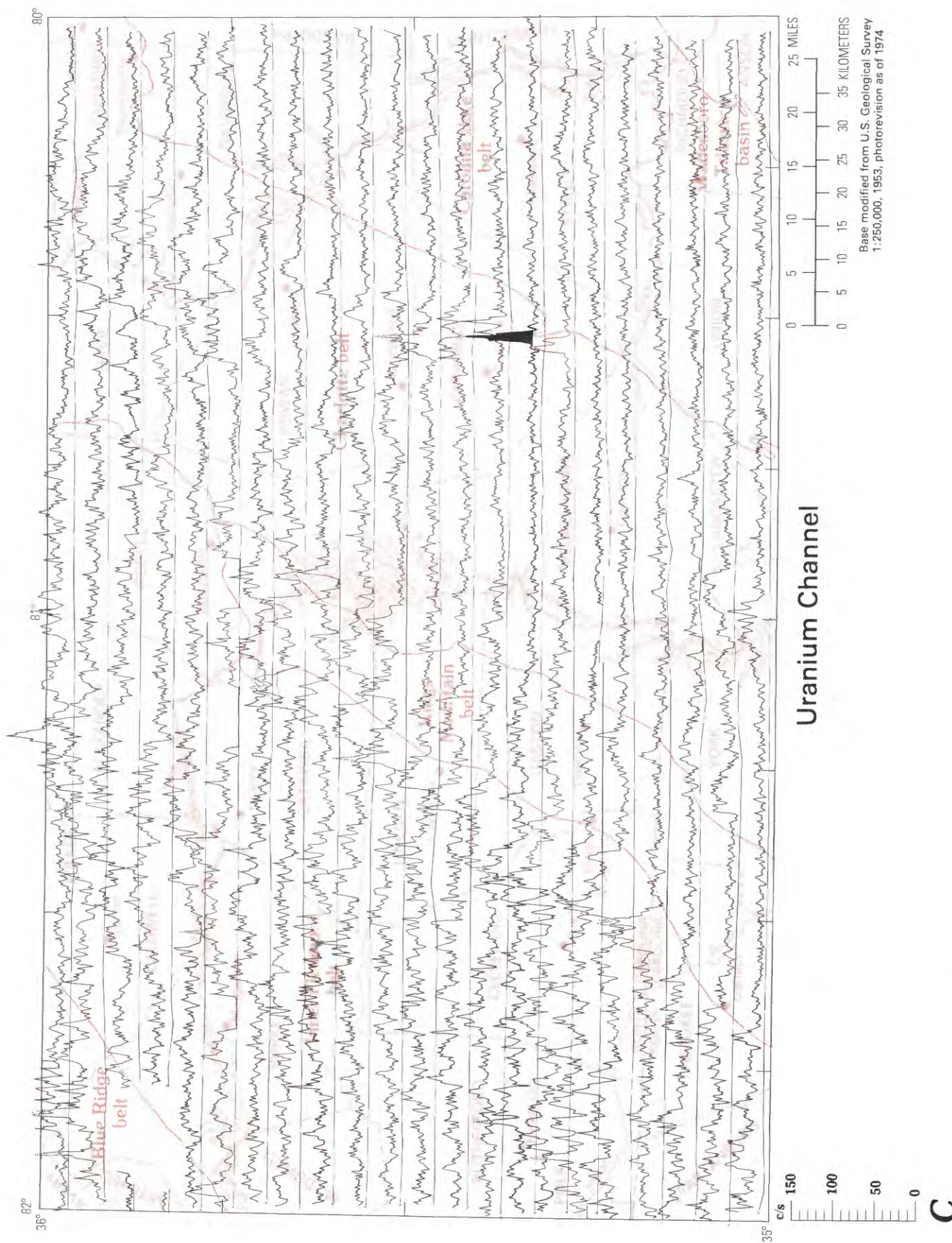


FIGURE 5. — Continued. C, Bismuth-214 (uranium) channel. Bar scale at the left of figure shows vertical scale in counts per second (c/s).

ANALYSIS OF GEOPHYSICAL MAPS, GENERAL

The fundamental requirement for discrimination of geologic units by geophysical means is the existence of significant contrasts in the rocks of those physical and chemical properties upon which the technique depends. The residual magnetic and Bouguer gravity maps reflect the physical properties, magnetization, and density of underlying rocks. These physical properties are related to the chemical composition of the rocks but do not correlate consistently with specific elemental concentrations. The gamma-ray intensities, on the other hand, are, under ideal conditions, a direct function of the concentration of potassium, thorium, and uranium in the rocks (provided chemical equilibrium has been maintained between concentrations of the elements and their daughter isotopes that are the actual gamma-ray emitters). Other factors that affect the gamma-ray signal include soil moisture, vegetation, chemical fertilizers applied to the soil, airborne gamma-ray emitters, and cosmic radiation.

A further difference in the surveys is that magnetic and gravity measurements are a function of the physical properties of rocks from essentially all depths (to the depth of the Curie point for magnetic material), whereas the aeroradioactivity surveys detect gamma-rays only from the uppermost several feet of ground. Therefore, gamma-ray maps are a tool for mapping variations of potassium, uranium, and thorium in the outer skin of the Earth's surface. Magnetic and gravity maps reveal information about large volumes of rock and can be used to deduce surface and subsurface structures up to crustal dimensions.

Several rock units within the Charlotte quadrangle produce distinct and complementary responses on the three geophysical maps (fig. 4). Several general rules are useful for interpretation of these maps. First, high gravity values indicate mafic rocks, and if coincident magnetic anomalies are of very high intensity, these rocks probably are gabbroic. The corresponding gamma-ray values of mafic rocks generally are low. However, the anomalies are frequently less distinct than the magnetic anomalies. Second, high gamma-ray intensities and coincident low magnetic and gravity values indicate felsic rocks. If the anomalies are oval or circular, postmetamorphic granitic plutons are indicated. However, a few moderately magnetic granitic plutons do occur in the southeastern Piedmont.

GEOPHYSICAL CHARACTER OF LITHOTECTONIC BELTS

The geophysical maps (fig. 4) show that the lithotectonic belts of the quadrangle (Goldsmith and others,

1988) display distinctive combinations of magnetic, gamma-ray, and gravity patterns and intensities reflecting geologic structures and physical and chemical properties of the rocks.

BLUE RIDGE AND INNER PIEDMONT BELTS

Geophysically, the Blue Ridge and Inner Piedmont belts look similar, although they are separated by the Brevard zone. The belts are characterized by a lack of intense shallow-source magnetic anomalies. This absence indicates that the surface rocks are only weakly magnetic. The absence of shallow magnetic contrasts allows long-wavelength magnetic anomalies from deep sources to predominate. The linear Brevard zone is shown by low-amplitude, linear magnetic anomalies.

These belts also are characterized by areas of very high gamma-ray intensity, exceeding levels in the other belts by a large factor. The highest values are in a broad zone along the center of the Inner Piedmont belt and in a smaller zone in the Blue Ridge belt. The spectral character of the gamma-ray anomalies in the Blue Ridge and Inner Piedmont belts differs from the spectral character of the strong anomalies over granite plutons in the Charlotte belt. High thorium and uranium levels dominate the former two belts, whereas high potassium dominates the Charlotte belt over the late Paleozoic granite plutons (such as the Churchland pluton, which has only moderate levels of thorium and uranium) (fig. 5).

Monazite, a rare-earth-thorium phosphate, is the mineral responsible for most of the intense thorium anomalies in the Inner Piedmont belt. It occurs as placer deposits and as an accessory mineral in granitic intrusions and schists and gneisses of high metamorphic grade. The gamma-ray maps probably accurately show the distribution of monazite both in situ and in placer deposits within the quadrangle. Areas of likely maximum concentrations of monazite can be deduced from the intense anomalies on either the total-count map (Daniels and Zietz, 1982) or the thorium-channel profiles (fig. 5). The latter give a more specific indication of monazite, but these flight lines are spaced 3 mi apart, whereas the total-count data, which include contributions from uranium and potassium sources, have higher spatial resolution (1-mi spacing). The four most intense thorium anomalies on the profiles are emphasized by shading in figure 5B. The most intense is located 2.5 mi northwest of Toluca, N.C.

KINGS MOUNTAIN AND CHARLOTTE BELTS

The Kings Mountain and Charlotte belts are both characterized by moderate to intense, short-wavelength magnetic anomalies and by a distinct pattern of intense magnetic, gamma-ray, and gravity anomalies due to

granitic and gabbroic plutons. Some of the more prominent granitic (potassium-rich) bodies that are readily apparent on the geophysical maps as low magnetic-gravity and high gamma-ray anomalies are the Churchland, Landis, Mooresville, Salisbury, High Shoals-Gastonia, Clover, and York plutons (A–G, respectively, on figure 4) (Goldsmith and others, 1988). The sharp contrast in gamma-ray levels between these plutons and relatively mafic country rocks makes the gamma-ray map a particularly valuable aid in the geologic mapping of the plutons. Prominent gabbroic bodies delineated by intense magnetic and gravity anomalies are the Concord, Mecklenberg, and Weddington plutons (H, J, and K, respectively, on figure 4). Most of the other intense magnetic highs are produced by smaller gabbroic bodies. The Kings Mountain belt also shows narrow, linear, north-northeast-trending magnetic anomalies caused by fold structures. Trends of magnetic and gamma-ray anomalies appear to be more random in the Charlotte belt due to the disruption of preintrusive regional trends by the many crosscutting plutons. Excluding the high gamma-ray level over the granite plutons, the overall low gamma-ray intensity of the Kings Mountain and Charlotte belts indicates that the average surface rocks are fairly mafic. One strong potassium anomaly in the Charlotte belt (shown shaded in figure 5A) is not over a pluton and may indicate hydrothermal alteration.

CAROLINA SLATE BELT

Long-wavelength magnetic and gravity anomalies and low to moderate gamma-ray levels characterize the Carolina slate belt. Rocks at the surface, and probably extending to a depth of at least several kilometers, are relatively nonmagnetic, except for diabase dikes of Mesozoic age. The dikes produce northwest-trending linear magnetic anomalies and probably cause many of the minor bends in the magnetic contours. Diabase dikes are present, although less abundant, in other belts (Goldsmith and others, 1988) but generally do not produce readily identifiable magnetic anomalies; this absence is partly because of suppression by more intense anomalies generated by plutonic or other rocks and because of competing strong magnetic trends, as in the Kings Mountain belt.

WADESBORO BASIN

The Triassic Wadesboro basin is characterized by low magnetic, gravity, and gamma-ray levels. Low gamma-ray levels over the basin distinguish it from the adjacent Carolina slate belt, to which it is otherwise geophysically similar.

NOTABLE SPECTRAL GAMMA-RAY ANOMALIES

Across most of the Charlotte quadrangle, the gamma-ray intensity (in counts per second) of the thallium-208 (thorium) channel generally equals or exceeds 2 times the intensity of the bismuth-214 (uranium) channel. There are two areas overlying specific granitic plutons, however, where uranium intensity compared to thorium intensity is notably stronger. One area is along the eastern edge of the Inner Piedmont belt over both the Cherryville and Sunnyside plutons (Goldsmith and others, 1988) and thereby suggests a genetic association between the two. This area also contains strong uranium anomalies at several locations along strike from the northern terminus of the elongated Cherryville pluton, suggesting possible outliers of that body.

The second area is in the eastern part of the Charlotte belt over parts of several plutons of the Salisbury Plutonic Suite (Goldsmith and others, 1988). The highest intensity of the uranium channel in the Charlotte quadrangle (shaded on figure 5C) was recorded over one of these plutons, the Bogers Chapel pluton (Bates and Bell, 1965), about 7 mi south-southeast of Concord, N.C. Several other occurrences of high uranium relative to thorium are found within the Churchland pluton north of and approximately along strike from the Salisbury pluton. This relationship suggests that bodies of the older Salisbury Plutonic Suite may have been incorporated into the younger Churchland pluton.

ANOMALIES DUE TO SUBSURFACE FEATURES

The geophysical feature of largest areal dimensions and amplitude within the Charlotte quadrangle is the Appalachian gravity gradient, which extends nearly the full length of the Appalachian orogenic belt. In the southern Appalachians, the gradient is expressed as a northwest-southeast negative-positive Bouguer anomaly pair connected by a long gravity gradient. Within the Charlotte quadrangle, the positive values occur over the Charlotte and Carolina slate belts, and negative values (less than –100 mGal) occur over the Blue Ridge belt. Hutchinson and others (1983) studied this feature by means of a northwest-trending profile, 373 mi long, which crosses the Charlotte quadrangle. They showed that seismic-refraction data suggest thickening of the crust by nearly 6 mi in the region of the deep negative anomaly, and they constructed a gravity model of a crustal root that matches the amplitude and shape of the negative anomaly. Seismic data are ambiguous, however, about the source of the positive anomaly. Three different models were found to satisfy equally well the positive part of the anomaly: a suture zone, a mantle upwarp, and a shallow body.

The most striking geophysical feature of the Carolina slate belt in the Charlotte quadrangle is the correspondence of a large double bull's-eye magnetic anomaly with a gravity anomaly of similar shape and position (*L*, fig. 4). The source is interpreted to be a large mafic body at depth. It is significant that the trend of these anomalies seems to correspond roughly to northeast-trending axes of broad, open folds in the rocks of the slate belt. Therefore, the mafic source of the anomalies may have been deformed along with the slate belt rocks. The source may be basement rock, perhaps a slice of oceanic crust, upon which the Carolina slate rocks were deposited. Graphic depth estimates based on magnetic data, although necessarily crude, suggest that the top of this source lies at a depth of 3 or 4 mi, whereas gravity modeling suggests approximately 2.5 mi. Numerous small exposed gabbro bodies distributed along anticlinal axes in the zone of northeast-trending open folds may be related to this deep mafic source.

The geophysical maps can be used to delineate shallow structures fairly confidently. An intense magnetic anomaly located about 10 km east of Davidson, N.C., and an associated gravity anomaly (*M*, fig. 4) indicate a geologic environment similar to that at the Mecklenburg pluton (Goldsmith and others, 1988), suggesting that the area is underlain by a gabbroic pluton of about the same areal dimensions as the anomalies. Geologic mapping by Milton (*in* Goldsmith and others, 1988), however, revealed mostly quartz diorite and granodiorite at the surface, with only two small bodies of gabbro and metagabbro. The intensity and steepness of the magnetic gradients suggest that one or both of the two gabbro bodies may be a cupola of a gabbroic pluton that is capped by a thin veneer of country rock.

CONCLUSIONS

Both the magnetic and gamma-ray maps of the Charlotte quadrangle are useful qualitative tools for assisting geologic mapping, delineating structural trends, and revealing average unit compositions. These are especially strong tools for mapping the granitic and gabbroic plutons in the Charlotte and Kings Mountain belts. Gravity data are best suited in the Charlotte quadrangle for modeling subsurface structure. Total-count maps and thorium-channel spectral gamma-ray data are important aids in identifying monazite occurrences. The relative intensities of the thorium and uranium channels suggest common sources for certain isolated granitic bodies (in particular, the Cherryville and Sunnyside plutons) and possible outliers of the Cherryville not found in geologic mapping.

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GEOCHEMICAL AND HEAVY-MINERAL SURVEYS

By WALLACE R. GRIFFITTS, KAREN A. DUTTWEILER, and JESSE W. WHITLOW

METHODS OF TAKING AND PROCESSING SAMPLES

Stream sediments were used as the basis of the geochemical survey because they are the only sample medium that is likely to provide significant information about mineralization in a large area in a reasonable time and with a feasible number of samples. About 2,500 samples were taken, most of them within 2 mi of the heads of streams. Normally, in sampling, gravels were dug to the bottom of the alluvial bed or to a compact clay layer. The coarsest material (boulders, cobbles, and coarse pebbles) was excluded, and about 4.5 kg (10 lb) of clay to fine-gravel-size sediment was collected. Heavy minerals were separated from this material by panning at the sample site. The concentrates were sieved to minus 20-mesh in the laboratory, further refined by bromoform separation, and split into three fractions with a Frantz magnetic separator (15° side slope, 25° forward slope). The separations were made at settings of 0.5 and 1 A, yielding fractions we call M.5 and M1, respectively, and a nonmagnetic (NM) fraction at the 1-A setting.

Mineral proportions in each fraction were estimated with a binocular microscope. Minerals of special interest were identified by petrographic microscope or X-ray diffraction. Each fraction was analyzed semiquantitatively for 31 elements with a six-step d-c arc, optical emission spectrographic method (Grimes and Marranzino, 1968).

This section on geochemical and heavy-mineral studies summarizes the data contained in a number of Open-File Reports on individual elements and heavy minerals. The present authors had primary responsibility for all but one of the individual reports; they were helped in report preparation by Theodore Botinelly (for copper and lead), J.D. Hoffman (for beryllium, cobalt, lithium, and molybdenum), and D.F. Siems and L.O. Wilch (for antimony-arsenic-bismuth-cadmium, niobium, tin, tungsten, and zinc). Siems also had primary responsibility for the report on thorium-cerium-monazite and coauthored the reports on barium, beryllium, cobalt, copper, gold, and lead (see references at the end of this section for specific authorships).

In addition to the work done by the authors listed above, A.L. Meier collected a number of concentrate samples, C.L. Bigelow performed mineral analyses, and Steven McDanal and Christine McDougal were responsible for entering and editing data about localities and spectrographic results in a computer file. Many geochemical maps were subsequently plotted from this file by H.V. Alminas, L.O. Wilch, and J.D. Hoffman.

All other geochemical analyses were made of minus 100-mesh stream-sediment samples collected by Van Price and his associates and reported by Heffner and Ferguson (1978) and Ferguson (1979). This sample material is referred to as "silt" in this report.

GENERAL PROPERTIES OF SAMPLES

The minus 100-mesh and the heavy-mineral-concentrate samples provide different types of geochemical information. Generally, the minus 100-mesh samples provide information about the lithology of the drainage basins, and the heavy minerals provide more explicit information about mineral deposits. Thus, high magnesium and vanadium contents of silt samples indicate mafic rocks, and high potassium contents indicate granitic rocks or phyllites. Such inferences also may be made about the major geologic belts. For example, the Charlotte belt as a whole is characterized by high vanadium content (R.H. Carpenter, 1980, oral commun.). Concentrates, unlike silt samples, provide enhanced contrasts in metal values between mineralized and barren drainage basins as shown by values of copper and most other metals, thereby making mineralized terrane easier to recognize. High values of lead, zinc, cobalt, and tungsten in the two sample media (silt and concentrates) are not usually found in the same areas; high contents of metals in concentrates commonly relate more clearly to mineralized districts than do high metal contents in the silt samples. Heavy-mineral concentrates are especially valuable for estimating potential for gold and cassiterite deposits because the heavy-mineral assemblages give clues to the concentrations of these minerals and their recoverability. These indicators are particularly important for tin because small amounts of tin are widespread

in nonmineralized rocks, whereas the presence of cassiterite indicates mineralization (albeit not necessarily of commercial grade). Gold and cassiterite do not normally occur, even in small amounts, in ordinary rocks, and therefore they have no "background" values; one particle of either mineral in a concentrate sample indicates gold- or cassiterite-bearing mineralized rock upstream from the sample site.

Most common ore minerals are mainly in the NM fraction of concentrate samples. This fraction also contains zircon, sillimanite, kyanite, spinel, apatite, sphene, and the titanium-oxide minerals. It is generally the most useful fraction. The M1 fraction is largely monazite in the Inner Piedmont belt (fig. 2).¹ East of the Inner Piedmont belt, the M1 fraction of concentrates contains abundant epidote, clinozoisite, mixed mineral grains (including ilmenite partly converted to leucoxene), staurolite, locally abundant spinel, and monazite. The M.5 fraction contains abundant garnet in the Inner Piedmont belt, dark ferromagnesian minerals in the Charlotte belt, and ilmenite in most belts of the quadrangle.

NEWLY FOUND MINERAL DISTRICTS

Three previously unsuspected geochemical features were found during the Charlotte quadrangle geochemical survey: widespread tin mineralization associated with high values of niobium, beryllium, and other elements in the Inner Piedmont belt and in the Salisbury, N.C., area within the Charlotte belt; the association of cobalt with niobium, south of Salisbury in the Charlotte belt, and cobalt without niobium, east of Gaffney, S.C., in the Kings Mountain belt; and base-metal mineralization consisting of zinc, lead, and cadmium in the Charlotte belt near Thomasville in the northeastern corner of the quadrangle (see fig. 1 for locations).

Tin has long been known to be present in the tin-spodumene belt that passes through Kings Mountain, N.C. (Kesler, 1942), but a large tin-bearing area extending westward from Kings Mountain to the western edge of the quadrangle was not known before our work. Concentrations of tin, bismuth, and beryllium also are found in stream sediments north of the tin-spodumene belt. In addition, two granite plutons, one at Brown Mountain in the Blue Ridge belt near the northwestern corner of the quadrangle, and the other a few miles south of Salisbury, N.C., in the Charlotte belt (pl. 1), are sources of tin-rich minerals in the streams that drain them. At Brown Mountain, the tin mineral is cassiterite, accompanied by columbite; near Salisbury, both ixiolite

((Ta, Nb, Sn, Fe, Mn)O₂) and cassiterite are present. Cassiterite-bearing heavy-mineral concentrates collected in the southeastern corner of the quadrangle near the Fall Line (which is just outside the quadrangle) suggest that tin placers may be present near this line elsewhere in the Carolinas. The spatial association of cobalt with niobium in the Salisbury area is very close. A comparison of the distribution of the two shows a striking coincidence of metal. Rich sample sites seemingly contradict the normal clean geochemical separation of the two metals. Cobalt is generally associated with mafic igneous rocks and niobium with light-colored granites and alkalic rocks. The absence of detectable magnesium (less than 0.5 percent) in cobalt-rich magnetic concentrates shows the lack of ferromagnesian minerals and therefore of mafic rocks in the cobalt-bearing drainage basins. The cobalt is quite out of place in this environment, which instead is more typical of one in which niobium is normally found. Until this aberrant behavior is explained, we must recognize the possibility that cobalt may locally be sufficiently concentrated to form ore deposits. No cobalt-rich mineral has been identified in the area, but the presence of large amounts of manganese in the heavy-mineral concentrates that have high cobalt contents suggests that the cobalt may be held in black manganese-oxide minerals, some of which commonly scavenge large amounts of cobalt. The cobalt east of Gaffney, S.C., is in concentrates that contain unusually large amounts of zinc. Iron was mined in this area during the 19th century from at least three types of deposits, one of which is gossan, providing independent evidence that the area has been mineralized.

A cluster of heavy-mineral concentrates collected near Thomasville in the northeastern corner of the quadrangle yielded high values for zinc, lead, cadmium, and copper. Two of the concentrates contain sphalerite, and two contain detectable silver. The pale color of the sphalerite suggests that the mineralization differed from that which produced dark-brown sphalerite at the Silver Hill mine (see fig. 6) and elsewhere in the Piedmont.

GENERAL CHEMICAL FEATURES OF THE QUADRANGLE

Two broad geochemical provinces were found in the Charlotte quadrangle, one of gold and sulfide-forming (thiophile) metals and one of oxyphile elements.

The general distribution of the sulfide-forming metals (copper, lead, zinc, and cobalt) is shown in figure 6. Lead attributable to radioactive decay in monazite was disregarded in outlining the areas characterized by having base metals. The part of this area that trends about east-west through the southern half of the quadrangle also contains gold and is the broadest part of the Appa-

¹Locations referred to in this section on geochemical and heavy-mineral surveys are shown in other sections in this volume if they are not shown in a figure accompanying this section.

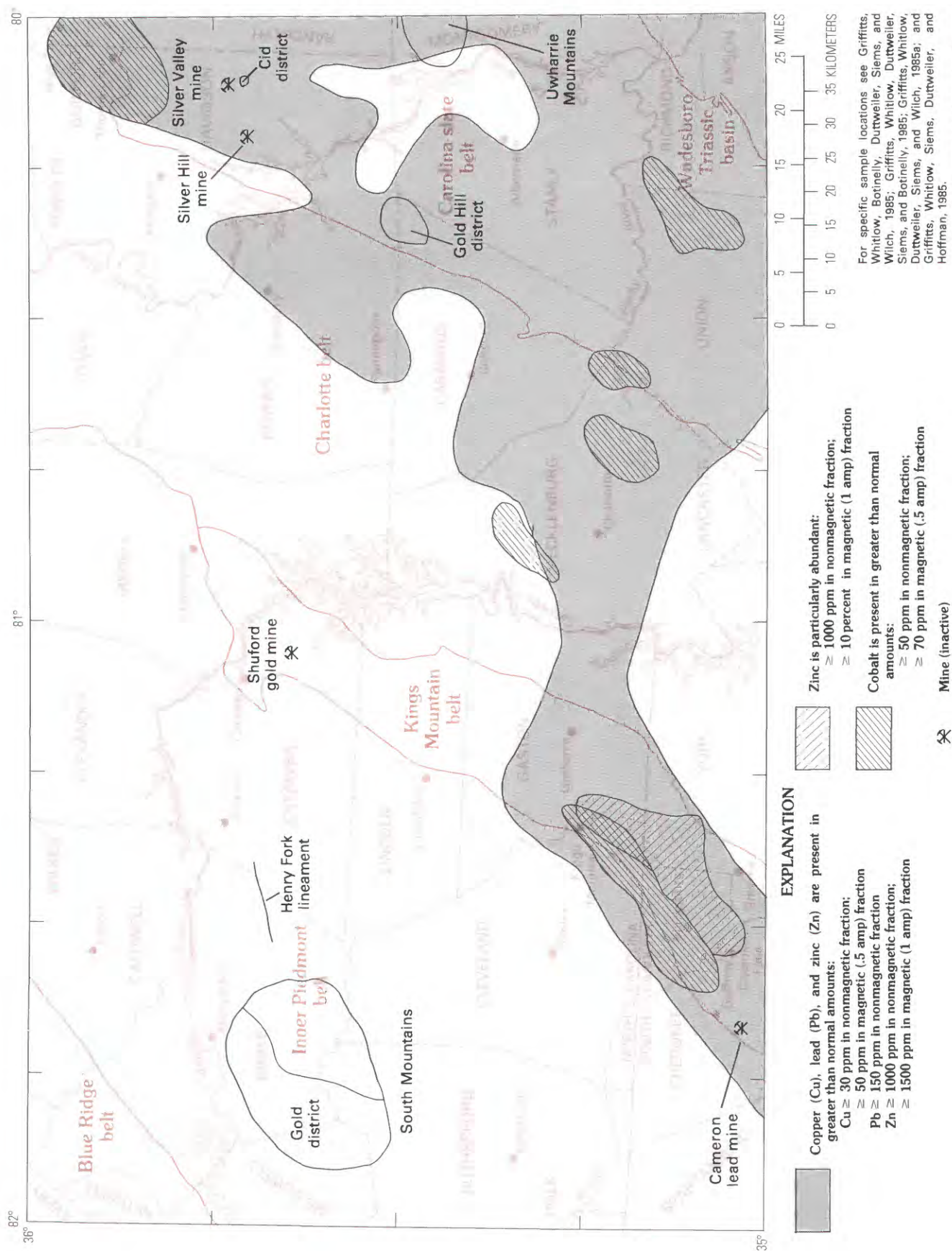


FIGURE 6. — Areas of the Charlotte quadrangle in which a large proportion of heavy-mineral samples contain abnormal concentrations of copper, lead, zinc, and cobalt.

lachian gold belt. Furthermore, all but one of the heavy-mineral concentrates containing detectable arsenic are located in this area, and many of the concentrates yielded bismuth. However, bismuth is not strongly restricted to this base-metal area.

Areas of concentration of the oxyphile elements (beryllium, niobium, and tin) are shown in figure 7. The areas overlap slightly with the areas of base metals. Abnormal concentrations of bismuth and lithium also are present in these areas but not necessarily in the same samples as the very high concentrations of beryllium, niobium, and tin. Bismuth is closely associated with tin in the tin-spodumene belt.

CONTAMINATION

Metals and minerals have been added to streams in the Charlotte quadrangle during the last 300 years through hunting, building of roads, and dumping of trash. Cans, nails, small scraps of iron, and other iron and steel artifacts are generally large enough to be seen and are removed during sampling and panning. Smaller ferruginous pieces are removed during the first magnetic separation, even if they have been largely converted to rust. The oxidation products of thin coatings on iron or steel cans and sheet iron probably are eliminated in tiny grains with clay and silt during panning. Thick layers and lumps of solder may be present with other lead artifacts.

To minimize the incidence of such contamination, we took samples upstream from bridges and have considered the presence of other dumping sites upstream from sample sites in evaluating our data. Nonmagnetic fractions of concentrates were examined by microscope to detect possible contamination by lead, copper, and tungsten artifacts. Such materials were removed before analysis, and their presence was noted. Even with these precautions, slightly higher values of lead are present in concentrates that contained white oxidized lead shot. We also evaluated the common alloying elements (antimony, arsenic, bismuth, and tin) in samples that are exceptionally rich in lead. Unfortunately, most of these metals can be associated with lead in ore deposits as well as in artifacts; other factors, geologic and geochemical, must be considered when using such ambiguous data.

Lead was found in NM fractions in the forms of round shot, bullets, fragments of automobile batteries, and irregular pieces and shavings and in various forms of solder and soldered seams. Copper was found as plating on lead shot or bullets and as pieces of wire and lamp cord, many of which are coated by cuprite or are completely oxidized. Tungsten was found as a small piece of lamp filament. The only potentially troublesome mineral contamination is artificial corundum from various abrasive materials, observed as sharply angular reddish-

brown fragments instead of the hexagonal gray, blue, or pink prisms and flakes of natural corundum.

Addition of metals to stream sediments by mining is localized near mine sites, but the metal or mineral was present in the drainage area before mining took place, so contamination may have increased the amounts of metal in the sediment without adding any new substance, in contrast to contamination by artifacts. The largest mining operations at present are in pegmatites of the tin-spodumene belt at the southeast edge of the Inner Piedmont belt and in marble of the Kings Mountain belt. During the mining of the lithian pegmatites, small amounts of cassiterite, columbite, spodumene, and beryl have probably been added to stream sediments in amounts sufficient to enhance values of tin, niobium, lithium, and beryllium in our analyses. Mining of mica, feldspar, quartz, and clay did not change the content of metals detectable in stream sediments because deposits of these commodities have very low contents of the heavy metallic minerals and beryl. The quarrying of marble may contribute dolomite and small amounts of accessory minerals, particularly mica, amphibole, garnet, and pyroxene. Most of the metal mines and prospects in the Charlotte quadrangle are much smaller than the spodumene, mica, and stone quarries and thus had little observable effect on our samples. Small amounts of galena were found at several mines near the northwestern corner of the quadrangle; malachite was found in the same area and near Cherokee Falls, S.C.; and probable chalcopyrite was found in small amounts at the Shuford gold mine in Catawba County, N.C., at a marble pit near the town of Catawba, N.C., at prospects near Cherokee Falls, and south of Gold Hill, N.C. (fig. 6). We have little evidence that these minerals contaminated our samples.

SUMMARIES OF INDIVIDUAL MINERALS AND ELEMENTS

GARNET AND OTHER METAMORPHIC MINERALS

The metamorphic minerals are useful as indicators of geologic environment and exploration targets. In many places, metamorphic isograds may be delineated more accurately by using heavy-mineral concentrates than by observations of rocks containing only small amounts of the metamorphic minerals. The metamorphic index minerals also can be used to identify sediments that have been washed into modern streams from old terraces or other old erosion surfaces. Most of the staurolite, garnet, and kyanite in the Carolina slate belt is recycled and is quite out of place with the greenschist-facies rocks; some garnet and kyanite, however, have been observed in rhyolites of the Carolina slate belt outside the Charlotte quadrangle (T.L. Klein, 1984, written commun.). The

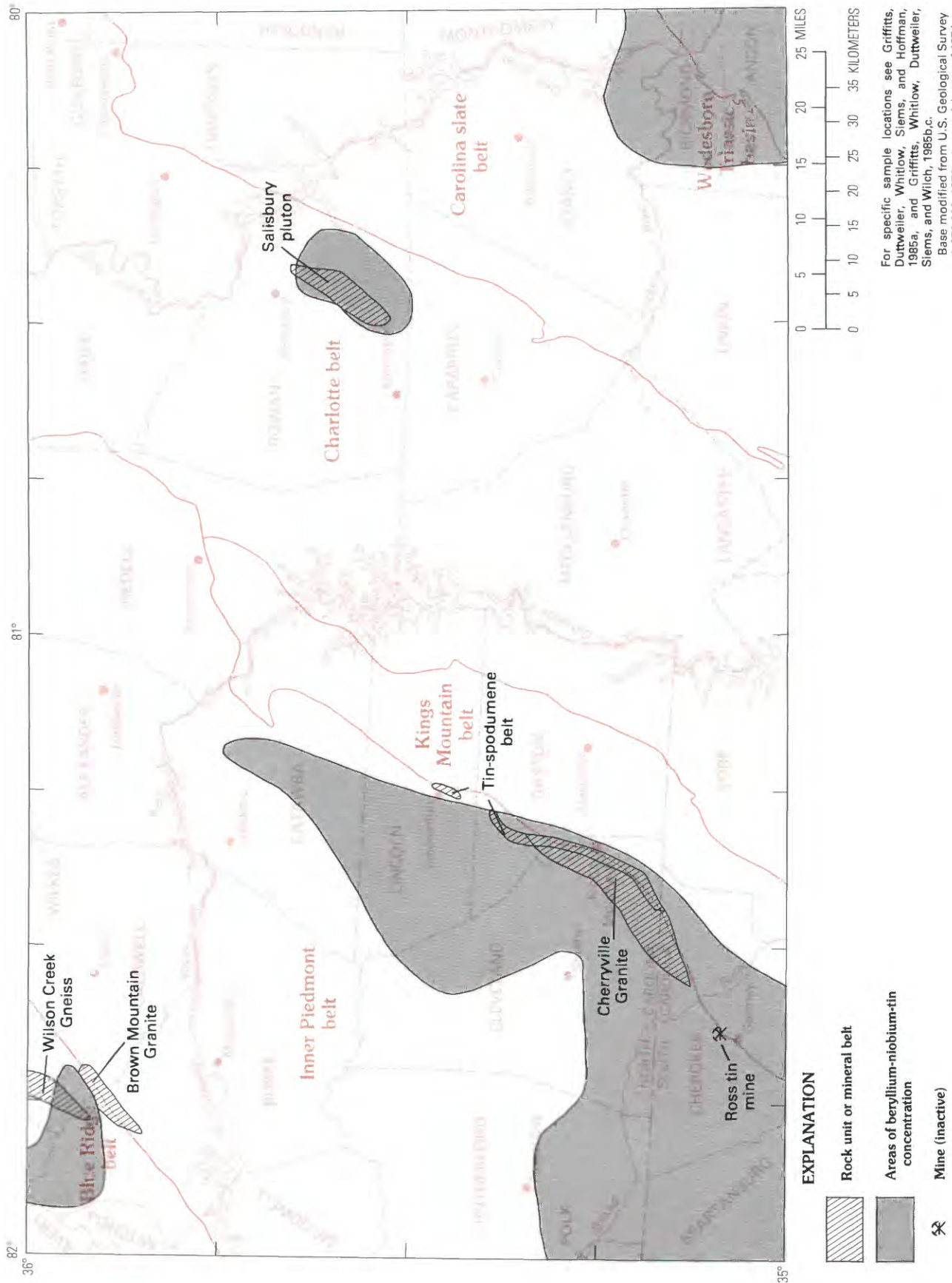


FIGURE 7.—Areas of the Charlotte quadrangle in which heavy-mineral samples contain concentrations of beryllium (>20 ppm), niobium (>20 ppm), and tin (>300 ppm).

nearly complete blanket of these minerals in the eastern part of the Charlotte quadrangle may well represent a "micro-lag gravel" remaining after erosion of an inland extension of the Coastal Plain.

Garnet is the most widespread of the metamorphic minerals found in our heavy-mineral concentrates, being indigenous to the Blue Ridge, Inner Piedmont, and Kings Mountain belts. It also is associated with some gold deposits in the eastern part of the Charlotte belt. Garnet grains in the Piedmont province acquire a brown limonitic crust by weathering, below which the garnet is strongly etched in a manner that is characteristic of saprolitic or lateritic terranes. The crust breaks off during stream transport and is missing from the recycled garnet found over much of the Charlotte and Carolina slate belts.

Kyanite is present in many of the rocks of the Kings Mountain belt, has been mined in one place, and is a potential resource elsewhere (see section "Kyanite and sillimanite in high-alumina quartzite of the Battleground Formation"). Nonmagnetic heavy-mineral concentrates from alluvial samples that are moderately uniform in size and granularity and that are collected from streams that drain potential kyanite resources have more than usual amounts of kyanite and rutile, and these minerals are coarser than in most other places. Such data permit the selection of areas in the Kings Mountain belt worthy of further exploration for kyanite deposits, but not areas in and near the Carolina slate belt, because kyanite there has been recycled from older sediment and little, if any, is native to slate-belt rocks. The presence of small amounts of kyanite and topaz in or near the pyrophyllite deposits that are just east of the Charlotte quadrangle suggests that these minerals may be useful guides to pyrophyllite deposits, which would be difficult to detect by either mineralogical or geochemical surveys.

Sillimanite is a major component of many schists of the Inner Piedmont and is a minor component of some granitic and gneissic rocks. It was carried eastward from the Inner Piedmont by streams, so the eastern boundary of areas containing sillimanite in heavy-mineral concentrates is irregular and unrelated to the underlying formations. During stream transport, sillimanite grains break up readily into tiny pieces and therefore may have been overlooked in some concentrates from the Charlotte and Carolina slate belts. The elongate shape of areas that yield sillimanitic concentrates probably marks former routes of transport across the Piedmont province and may be useful in tracing ancient drainage systems. East of the Inner Piedmont belt, sillimanite of contact-metamorphic origin occurs near some granitic plutons (Espenshade and Potter, 1960), but sillimanite from this environment is in larger grains and is more abundant

than sillimanite carried east from the Inner Piedmont belt.

Staurolite is indigenous to most of the Kings Mountain and Blue Ridge belts and is present in some streams in both the eastern and western parts of the Inner Piedmont belt (Overstreet and others, 1963). Some staurolite in the western part of the Inner Piedmont, however, was carried in streams from bedrock sources in the mountains of the Blue Ridge belt. In the Shelby, N.C., area, staurolite is found in saprolite only in the general vicinity of young pegmatites that yield sheet mica (Griffitts, 1958). A cluster of sites near Gaffney, S.C., that contain minor amounts of staurolite may be related to tungsten mineralization in that area. Therefore, the distribution of staurolite in the Inner Piedmont may be a guide to sheet mica pegmatites or nonpegmatitic tin deposits. Staurolite is widespread in concentrates from the Carolina slate belt but is largely or entirely extraneous, brought eastward by streams from its original bedrock sources.

Andalusite has been found in vein quartz and mica schist near the boundary between the Inner Piedmont and Kings Mountain belts and is present in many stream sediments of the Kings Mountain belt.

Scheelite is common in heavy-mineral concentrates of the quadrangle and may well have formed as a metamorphic mineral in the Inner Piedmont belt and as a vein mineral east of the Inner Piedmont. Scheelite is discussed in the subsection on tungsten later in this section. Likewise, zincian spinel, a metamorphic mineral that is the most widespread zinc-bearing mineral in our samples, is discussed later in the subsection on zinc.

LIMONITE PELLETS

Small, red to dark-brown limonite pellets were found in many concentrate samples. The pellets range in diameter from 1.5 to 3 mm. Some have concentric banding, and others have a dark-brown, well-cemented core surrounded by softer yellow-brown material. Most are reddish-brown in color and fairly homogeneous.

Limonite pellets are nearly ubiquitous in the heavy-mineral concentrates from the eastern two-thirds of the Charlotte quadrangle and constitute more than half of some concentrates, but they are rare in the Inner Piedmont belt and are found mainly on flat hills near the eastern edge of the belt, where they may be products of weathering under the old Piedmont Plateau. Limonite pellets also are uncommon in the Blue Ridge belt.

The primary source areas and manner of distribution of the pellets are uncertain. They may have formed in the stream sediments or may have been washed into the present streams from soils in which they were formed. Most of the soils in the quadrangle are acidic and are not

reported to contain iron-oxide or manganese-oxide concretions. Neutral soils are reported to contain concretions but yielded limonite pellets in only a few heavy-mineral concentrates. Presumably, then, limonite pellets are more widespread in soils than is indicated in the literature on soils of the area and were formed in the stream sediments, or, like garnet and other metamorphic minerals, were carried in ancient streams to present-day hills and then washed into the modern streams during the present erosion cycle.

We deduce that limonite pellets may be a useful sample medium for geochemical exploration for metallic deposits. If these concretions formed in soils that are now being eroded by modern streams, then their base-metal contents probably reflect the base-metal contents of the soils from which they came. If the pellets formed within the stream sediments, however, then they probably have base-metal contents that reflect the metal contents of the streamwater, which, in turn, vary with the metal contents of neighboring rocks. If pellets formed during Tertiary time and subsequently were washed into modern streams, they might have scavenged metal after entering the streams.

COPPER

In concentrates from 57 localities, cuprite (the only copper mineral recognized in the concentrates) occurs generally in thin red flakes, partly stained green. Copper has been spectrographically detected in many samples of concentrate and silt; in most places, values are especially low in silt (Heffner and Ferguson, 1978). The most frequently occurring values are between 5 and 10 ppm Cu and the highest value in 1,238 samples is 150 ppm Cu. These low values probably are the result of the thorough leaching of copper from the prevalent acidic soils before the clay and silt from the soils were washed into the streams. Cuprite occurs in NM fractions of concentrates that come from most mineralized areas east of the Inner Piedmont belt and have copper values of 50 ppm or more. Therefore, in areas not yet known to be mineralized, the presence of cuprite and copper values of 50 ppm or more are useful indicators in suggesting undiscovered areas of copper mineralization. Samples from the South Mountains gold district in the Inner Piedmont belt yield copper values of 10 to 30 ppm in NM fractions. Sparsely distributed samples from southwest and northwest of the South Mountains yield copper values of 50 to 100 ppm in NM fractions. The boundaries of the South Mountains gold district also correspond to copper values of 50 to 100 ppm in a number of M.5 fractions.

Samples from a large crescentic area, along the northwestern flank of the South Mountains and extending eastward on the north side of the mountains to the

vicinity of Hickory, N.C., contain 10 ppm or more copper in concentrates. Gold also has been found in concentrate samples in much of this area. The area overlaps the South Mountains gold district, establishing a pattern in the quadrangle consistent with the known association of copper and gold elsewhere (Emmons, 1940, p. 280). Gold and copper also are associated along a number of linear zones in the Inner Piedmont. Samples that yield magnetic (M.5) fractions containing more than 100 ppm Cu are clustered in the Gold Hill district of the Carolina slate belt and in a gold-producing area on the western side of the Uwharrie Mountains at the eastern edge of the quadrangle (fig. 6).

In general, relatively high copper values in silt and in NM and M.5 fractions of concentrates indicate copper-gold mineralization and, less consistently, lead-zinc mineralization. However, the M.5 fraction contains more copper than either silt samples or NM fractions and may therefore be a more reliable sample medium than the other two with which to identify copper-gold mineralization.

LEAD

Lead minerals are not common in the heavy-mineral concentrates. Cerussite derived from lead artifacts, and some apparently not related to artifacts, has been found in several places in the quadrangle, and pyromorphite, litharge, and plattnerite have been found at single localities.

The most important feature in the lead geochemistry of the Charlotte quadrangle is the high content of radiogenic lead (^{208}Pb derived by the radioactive decay of thorium) in the M1 fractions of heavy-mineral concentrates from the Inner Piedmont and Blue Ridge belts. Several hundred parts per million of lead have accumulated in thorium-rich monazite since the monazite formed several hundred million years ago. Zircon in Proterozoic rocks of the Blue Ridge belt also contains radiogenic lead in amounts of 100 ppm or more, formed by the decay of thorium in the zircon. Therefore, high values of such lead are not related to lead minerals or deposits.

We have eliminated most of the monazite from the NM and M.5 fractions by magnetically concentrating it in the M1 fraction. The NM fraction has little or no monazite and contains most of the lead minerals; therefore, its lead content is very useful as a guide to mineralization. Samples yielding NM fractions containing at least 1,000 ppm of lead are found in a continuous zone on the west, south, and east of the city of Charlotte, N.C. However, lead artifacts are common on the west side of the city and caused us to discount the lead values there, and lead values south of the city also may represent contamina-

tion. Those to the east may be related to gold mineralization.

A cluster of lead-rich NM samples (150–>1,000 ppm Pb) derived from mineralized rock was found in the Thomasville area of the Charlotte belt in the northeastern corner of the quadrangle, near the contact with the Carolina slate belt. These samples also have high cadmium, zinc, and copper contents and contain grains of sphalerite.

Samples having high lead values in the NM fraction are sparsely distributed along the northern part of the Gold Hill shear zone between the Charlotte and Carolina slate belts (pl. 1). This lead and associated, rather abundant zinc probably indicate that the shear zone is mineralized in places. Scattered high lead values in the Carolina slate belt, particularly near the southern and eastern edges of the quadrangle, probably reflect mineral occurrences in bedrock but in some cases may be due to contamination by artifacts.

In the Kings Mountain belt, samples yielding very high lead values are not common, and high values generally are not clustered. Three high values (1,000, 750, and 150 ppm) occur near the old Cameron lead mine south of Gaffney, S.C., and a group of samples with similar values occurs in an area of old iron prospects and mines east of Gaffney (fig. 6). In both places the values probably reflect the presence of mineralized bedrock.

Silt samples from the eastern part of the quadrangle have high lead contents in a broad zone that crosses the sheared boundary of the Charlotte and Carolina slate belts (Heffner and Ferguson, 1978). The highest lead contents, greater than 20 ppm Pb, are in the mineralized terranes in the mountainous area of the Uwharrie National Forest and near Gold Hill in the Carolina slate belt (fig. 6). Neither silt nor concentrate samples provide evidence of the important lead-zinc-silver mineralization at the Silver Hill mine in the Carolina slate belt (fig. 6). Also, the mineralization at the Silver Valley mine and vicinity (fig. 6) is shown rather inconspicuously or ambiguously by silt samples containing 20 to 30 ppm Pb and NM fractions of concentrates containing 100 to 1,000 ppm Pb.

ZINC

Three zinc-rich minerals occur in the Charlotte quadrangle: sphalerite, zincian spinel, and zincian staurolite; they are found in one or more of the three fractions made from the heavy-mineral concentrates. Zincian spinel is the most widespread of these minerals and is in both the NM and M1 fractions. The spinel in the NM fraction generally is blue and that in the M1 fraction generally is green because of differences in iron content. We have found sphalerite only in the northeastern and northwest-

ern corners of the quadrangle. Zincian staurolite is found in the M1 fraction, mainly in the Kings Mountain belt. No single sample medium or pattern consistently indicates where rocks have been mineralized. However, the likelihood of resource potential increases in areas where two or more zincian minerals, plus some other metallic mineral and favorable rocks, are present.

The most conspicuous feature on the geochemical map for zinc (Griffitts, Whitlow, and others, 1985a) is a large zinc-rich area adjacent to the western boundary of the Kings Mountain belt. Both NM and M1 fractions of the concentrates from this area contain zinc, but areas having the highest zinc contents in the two sample media do not coincide exactly. The zinc-rich NM fraction occurs largely within the Kings Mountain belt in the general area of iron prospects near Blacksburg, S.C., and in the area of gold deposits near Smyrna, S.C. The zinc-rich M1 fraction occurs more widely, over much of the Kings Mountain belt, but especially at the north end of the belt, where samples contain as much as 3,000 ppm Zn.

A cluster of samples in the Charlotte belt near the boundary of the Carolina slate belt in the northeastern corner of the quadrangle contains yellow, probably iron-poor sphalerite (NM fraction) and concentrations of other metals in addition to zinc: copper (NM and M1 fractions), cadmium, lead (as noted in the subsection on lead), silver, and tin (NM fraction). The sphalerite and metals probably were derived from veins. Sphalerite in the northwestern corner of the quadrangle is associated with the mineralized Shady Dolomite.

The mineralization of the Gold Hill district in the Carolina slate belt (fig. 6) is shown by moderate to high zinc contents of NM concentrates and of minus 100-mesh sediment (Heffner and Ferguson, 1978). The NM fraction of concentrates also has high copper and usually moderate lead values. The Silver Hill-Silver Valley-Cid area in the Carolina slate belt (fig. 6) falls within an area that yielded samples having at least 50 ppm Zn in the silts (Heffner and Ferguson, 1978). This is more zinc than is found in the immediately surrounding area, but no more than in much of the slate belt farther south; therefore, the zinc values near the Silver Hill deposit are not very distinctive. Values of associated copper and lead in these samples are not high. The geochemical data, therefore, do not clearly indicate this important mineralized area.

Areas at the west edge of the Carolina slate belt near the southern edge of the quadrangle yielded moderate to high zinc contents in minus 100-mesh samples (Heffner and Ferguson, 1978) and in several NM and M1 fractions. Nonmagnetic fractions also contain high copper and moderate to high lead values, and M1 fractions of some of the samples yield high molybdenum values. These results must reflect mineralization, some of which

may be related to the intrusion of small bodies of mafic rock.

High zinc contents of either the NM or M.5 fractions of concentrates from the Uwharrie Mountains at the eastern edge of the quadrangle (fig. 6) reflect known gold mineralization in that area.

GOLD

The Charlotte quadrangle extends across almost the entire width of the Appalachian gold belt at its widest part, so auriferous stream-sediment samples are common, but a spatial association between known gold deposits and gold-bearing alluvium is not evident everywhere (Gair and D'Agostino, 1986). Gold is in the form of tiny flat flakes in stream-sediment (concentrate) samples collected over Triassic rocks in the southeastern corner of the quadrangle, associated with well-rounded coarse grains of kyanite, rutile, and zircon, all of which are alien to the local environment and must have been recycled from sediments of the Triassic basin or the Coastal Plain. Gold in stream sediments in the area west of the Triassic basin and east of the Charlotte belt is in part reworked from older sediments, like the gold found in stream sediments overlying the Triassic rocks. Some of this gold probably was derived from unknown bedrock sources in the Carolina slate belt.

The scarcity of auriferous alluvial samples in some areas containing gold mines or prospects is not easily explained. It may indicate that gold in some areas is concentrated in a few veins large enough to be exploited but is not in broadly distributed minor veinlets that, when eroded, could give rise to widespread gold in stream sediments.

Visible gold was seen while panning or during microscopic examination of the samples, and nonvisible gold was detected with the spectrograph after removal of visible gold from the samples. This spectrographically identified gold is shown separately from the visible particulate gold in the gold resource-potential maps (Gair and D'Agostino, 1986) because of their different economic and possibly genetic significance.

Visible gold particles are seldom larger than 1 mm. Their shapes range from round to irregular, spongelike, or crystalline. The recycled particles obtained in the southeastern corner of the quadrangle are flat and very small. Pieces of gold characterized by sharp points or sharp edges between crystal faces probably are derived from nearby sources. All the gold is yellow, but the depth of color varies in different samples, likely indicating variations in purity.

The nonvisible or "occult" gold was found in many, but not all, of the samples that also contain visible gold. Likewise, visible gold was found in many, but not all, of

the samples containing "occult" gold. Tiny particles of "occult" gold must be embedded in another mineral, most likely limonite. Limonite is present in stream-sediment samples in several forms: cubic pseudomorphs after pyrite, irregular masses, and round pellets. The round pellets may be concretions formed in the soil. The cubes and perhaps the irregular pieces of limonite have formed from the oxidation of sulfides in primary bedrock mineral deposits, retaining any gold that was included in the sulfide minerals or that was trapped by the precipitation of limonite after local movement of iron in ground water.

An association of gold-bearing heavy-mineral concentrates with faults or related minor fracture zones is evident (1) in the South Mountains in the western part of the quadrangle, (2) along the Henry Fork lineament northeast of the South Mountains (fig. 6), (3) along the Brevard zone separating the Inner Piedmont and Blue Ridge belts (pl. 1), (4) in a zone east of Gaffney, S.C., in the southern part of the Kings Mountain belt, (5) possibly in the northern part of the Kings Mountain belt southeast of Hickory, N.C., and (6) near the Eufola fault northeast of Statesville, N.C. (pl. 1). As in many other regions, gold and copper generally are associated. Gold also is associated with cobalt, arsenic, and bismuth but more tenuously than with copper.

TIN

The total tin content of sediment samples is not as important economically as the content of tin that is easily recovered by simple mechanical means. Therefore, analyses of the tin content of heavy-mineral concentrates obtained by panning have provided the most suitable data for evaluating the tin resource potential of the Charlotte quadrangle. Our use of data from heavy-mineral concentrates is consistent with the fact that most of the world's tin comes from placer deposits.

Cassiterite and rutile are similar in appearance and occur together in nearly all tin-rich heavy-mineral samples. This similarity prevents accurate rapid visual estimates of the cassiterite contents of the samples. Spectrographic tin determinations made on NM concentrates are not affected by the possible presence of rutile in the sample but offer no proof that the tin measured is in cassiterite, the tin mineral that occurs in all tin ore deposits. However, cassiterite has been identified from all the tin-rich areas of the Charlotte quadrangle, and it can be assumed that most of the tin in the concentrates is in the form of cassiterite.

Cassiterite occurs in the heavy-mineral concentrates as lumps as large as 1.25 cm in diameter and as silt-size particles. Commonly, cassiterite is among the coarsest components of a pan concentrate. The main exception to this is in the Salisbury area of the Charlotte belt (fig. 7),

where the cassiterite is rather fine grained. The color of the cassiterite ranges from tan, pale red, or yellowish brown to very dark brown. The largest grains are subround and have dull, roughly abraded surfaces, whereas the smaller grains may be smooth and shiny. Many of the smaller grains are striated prisms that are very similar to those of rutile; however, all but the darkest cassiterite can be quickly distinguished optically by its lower refractive index, about 2.0 (much below the indices of rutile).

Five major areas in the Charlotte quadrangle yielded tin-rich concentrates from stream sediments derived from moderately well defined bedrock sources: (1) the tin-spodumene belt, (2) the Cherryville Granite pluton and vicinity (pl. 1), (3) a broad area southwest of the Cherryville pluton, (4) the Brown Mountain Granite in the Blue Ridge belt, and (5) the Salisbury pluton of the Salisbury Plutonic suite and vicinity in the Charlotte belt (fig. 7). Tin-rich concentrates found outside these major areas are of two types, those from source rocks within the Inner Piedmont belt² and those that have been derived from detritus on upland Piedmont surfaces, transported from distant bedrock sources. The main areas of such transported tin are a zone just east of the tin-spodumene belt, principally within the Kings Mountain belt, and another zone southeast of the Salisbury area, extending to the southeast corner of the Charlotte quadrangle and beyond to the edge of the Coastal Plain.

Tin-spodumene belt.—In the long-known tin-spodumene belt (fig. 7; Keith and Sterrett, 1931; Kesler, 1942), cassiterite is in pegmatite and greisen. The pegmatite has a fine-grained groundmass of albite, quartz, and muscovite, in which are embedded coarser microcline and, in many dikes, spodumene. Beryl, apatite, cassiterite, and columbite are widespread accessory minerals (Griffitts, 1954). The greisen is composed of white mica and quartz, and some contains cassiterite and beryl. Most greisen bodies contain much less than 1 percent cassiterite. The principal past tin production, about 130 tons of cassiterite-bearing concentrate from the Ross mine at Gaffney, S.C., was apparently derived mainly from greisen (E.B. Ward, 1948, oral commun.). Our heavy-mineral concentrates show that wolframite is present near Gaffney, S.C.; this tungsten mineral may be associated with the tin-beryllium mineralization there. The interrelationships of different types of mineralization in that general area are uncertain. Possibly, tungsten-tin-beryllium mineralization, including that at the Ross mine, was not synchronous with or closely related to the formation of the lithian pegmatite in the

tin-spodumene belt but was related to tin-beryllium mineralization to the west. Such mineralization in parts of the Cherryville pluton and in the southwestern part of the quadrangle is discussed in the next two subsections.

Cherryville pluton and vicinity.—A broad area of tin-rich stream sediment extends west from the tin-spodumene belt at about latitude 35°15', longitude 81°30', an area underlain largely by the Cherryville pluton (pl. 1). Tin is accompanied by niobium and beryllium but not molybdenum. South of about latitude 35°25' the pluton is rich in muscovite, probably as a result of hydrothermal alteration. Cassiterite was not found in the small number of pegmatite bodies in that area that were sampled for heavy minerals. The cassiterite of the stream-sediment samples probably is derived from feldspar-poor veins or greisen or from muscovitic granitic rock in the upper part of the pluton. Such rocks are common in other tin-bearing granitic plutons (Taylor, 1979). A tin-rich zone traceable southwestward from the Cherryville pluton may be part of a mineralized roof over the southwest-plunging pluton. The presence of molybdenum in this zone suggests that clusters of molybdenum-bearing concentrates farther west might overlie cupolas or small intrusive masses.

Southwestern area.—Tin-rich alluvium was found in a broad area extending westward from the vicinity of the Cherryville pluton to the western boundary of the Charlotte quadrangle. Beryllium, lithium, and sporadic molybdenum are associated with the tin of this area. Pods of greisen several centimeters thick and as long as 2/3 m were found in the gneiss and schist in the southeastern part of this area, but no potential tin source was seen in bedrock farther west and northwest. Some schists of this general area contain muscovite (Richard Goldsmith, 1980, written commun.), and a cluster of tin-rich samples is located near small bodies of muscovite-bearing granite, the largest centered at about latitude 35°15', longitude 81°50'. These granite bodies may contain disseminated grains of cassiterite. Tin was not found in the clusters of sheet-mica deposits (Griffitts and Olson, 1953, pls. 18, 19). Carr and others (1984) describe tin-bearing hornblende-biotite gneiss and quartz-feldspar-tourmaline rock found during exploratory drilling in this area done after the CUSMAP field work.

The tin-rich area clearly crosses the northeast- to north-trending rock units of the region, but the zone is in a very broad low-gravity area (Wilson and Daniels, 1980); this relationship suggests that the small exposures of muscovitic granite may be offshoots of a large deep intrusive mass, a possible source of tin in the area. Samples containing molybdenum may indicate small outcrops or buried intrusions genetically related to broad tin mineralization.

²Recent exploration in the Inner Piedmont belt west of the tin-spodumene belt by Billiton Exploration and Texasgulf Minerals and Metals, Inc. (Carr and others, 1984) has led to the recognition of tin-bearing hornblende-biotite gneiss and quartz-feldspar-tourmaline rock.

North of the Cherryville pluton in the Inner Piedmont belt, heavy-mineral concentrates contain less tin than over the pluton but do contain high values of beryllium and may help delineate the area affected by lithophile mineralization, even where tin is only a minor component.

Brown Mountain area.—The Late Proterozoic Brown Mountain Granite (pl. 1, unit Zcb) contains coarse microcline grains surrounded by small grains of albite, quartz, biotite, and microcline. Accessory minerals are fluorite, allanite (?), epidote, sphene, zircon, ilmenite, magnetite, and stilpnomelane (Bryant and Reed, 1970). The granite is cut by small dikes of quartz-perthite pegmatite and by quartz veinlets. Some joints have discontinuous films of fluorite. Cassiterite and columbite can be recovered by panning gravel from most creeks that drain the Brown Mountain Granite, but neither mineral has been found in the granite. Beryllium and niobium are associated with the tin in concentrates. Lithium is not present in silt samples.

The Brown Mountain Granite pluton is unconformably overlain by the Late Proterozoic Grandfather Mountain Formation; this relationship indicates that the upper part of the pluton was removed in Late Proterozoic time. There has, of course, been additional erosion since the Late Proterozoic, which with the earlier erosion would certainly have removed any intensely mineralized top that the pluton may have had. The pluton is largely bounded by faults or by the Grandfather Mountain Formation, so tin-bearing veins that may once have been peripheral to the pluton are no longer there. Thus, the probable source of the alluvial cassiterite is dispersed cassiterite in the pluton itself.

Salisbury pluton and vicinity.—The Salisbury pluton of the Salisbury Plutonic Suite (see pl. 1) consists of feldspar and quartz; minor chloritized ferromagnesian minerals; and accessory sphene, chlorite, biotite, monazite(?), calcite, muscovite, fluorite, epidote, and a "staurolite-like mineral" (Phillips, 1967). The niobium content of the granite is as high as 235 ppm (Fullagar and others, 1971) and is greatest in albite-rich rock in the northern and southern parts of the pluton. Fullagar and others also report that the same general areas contain abnormal yttrium, zinc, thorium, and vanadium. High tin values were found in NM concentrates from above and alongside the pluton; tin minerals identified in the concentrates are cassiterite and ixiolite ((Ta, Nb, Sn, Fe, Mn)O₂). The "staurolite-like mineral" of Phillips (1967) may be cassiterite.

BERYLLIUM

Beryl has been found in 11 pegmatite dikes that have been mined for muscovite in the Inner Piedmont belt

(Griffitts and Olson, 1953) and in other coarse-grained pegmatites in the same region (Wilson and McKenzie, 1978). The beryl typically is pale green or, less commonly, white and occurs in prisms about 2 to 40 cm wide. Fine-grained white beryl constitutes about 0.5 percent of the albitic pegmatites in the tin-spodumene belt. Because of its hardness, poor cleavage, and low density, beryl tends to remain in relatively large pieces in soil or sediment and not to appear in samples of heavy-mineral concentrate or silt. Beryl occurrences in soil or sediment are greatest in number near the lithium-bearing pegmatites of the tin-spodumene belt. Bavenite (Ca₄BeAl₂Si₉O₂₄(OH)₂), bertrandite (Be₄Si₂O₇(OH)₂), and bityite (CaLiAl₂(AlBeSi₂)O₁₀(OH)₂) are trace minerals within the pegmatites. Chrysoberyl, found as colorless to light-brown pyramidal crystals on the southern side of the South Mountains, is the only beryllium mineral found in this study that had not been found during the previous studies in the quadrangle.

The tin-spodumene belt (fig. 7) and an adjacent area of beryllium-rich stream sediments to the north are the most prominent features on the geochemical map for beryllium. Beryllium contents are very high in minus 100-mesh stream sediments of this extended area (Ferguson, 1979) and in NM concentrates. Beryl is not a heavy mineral, so the high beryllium contents of many heavy-mineral concentrates from this and other areas must be due to incomplete removal of beryl with the other light minerals or to the presence of heavier beryllium minerals, of which only chrysoberyl has been identified. The area containing beryllium-rich stream sediments extends about 25 km northeast from Lincolnton, N.C. (which is at the northern end of the well-defined pegmatite belt) to at least the northeast end of the Kings Mountain lithotectonic belt. The source rock of the anomalous beryllium northeast of Lincolnton has not been identified. Tin, bismuth, and tungsten also are found in concentrates from the area, and these elements may have a common source or related sources.

Beryllium-rich NM fractions of our concentrate samples were obtained from streams that drain Wilson Creek Gneiss and Brown Mountain Granite in the northwestern part of the quadrangle (fig. 7; pl. 1). In general, beryllium in these concentrates is accompanied by niobium and, near the Brown Mountain Granite, also by tin. The Brown Mountain Granite contains accessory fluorite, which is interesting because nearly all nonpegmatitic fluorite granites in the Western United States are accompanied by beryllium minerals. However, despite the beryllium-rich NM fractions, no beryllium minerals have yet been identified in the Brown Mountain Granite area. Beryllium-rich concentrates also are associated

with the fluorite-bearing Salisbury pluton, along with high contents of tin and niobium, but no beryllium mineral has been found there, either.

There is an area of beryllium-rich silt (Ferguson, 1979) in the north-central part of the Charlotte quadrangle, east of the deposit of spodumene (rarely hiddenite) near the town of Hiddenite (fig. 7) and away from the area of beryllium-bearing pegmatites in Alexander and western Iredell Counties. As in samples from the Brown Mountain Granite and Salisbury pluton, no beryllium minerals have been identified where there are high beryllium contents, and the nature of the source rock is unknown.

Because several of our beryllium-rich samples are from an area of Triassic sedimentary rocks in the southeastern corner of the quadrangle that are not plausible hosts for primary beryllium deposits, we suggest that such concentrates probably contain recycled detritus from a distant primary source. Other beryllium-rich concentrates in the eastern part of the Charlotte quadrangle may be derived from recycled sediment or from deposits that are entirely unknown.

A large area of beryllium-rich (3 ppm or more Be) silt samples near the eastern edge of the quadrangle follows northeast-trending folds involving the Cid Formation.

In general the higher beryllium contents of minus 100-mesh silt correspond only to the largest known area of beryllium mineralization, that of the tin-spodumene belt. In other areas, the beryllium content of silt is ambiguous. Thus, the Brown Mountain area is well outlined by silt with 2 ppm Be, but similar values are found in silt in areas having no known beryllium mineralization. As noted in an area near the Cid Formation, rather high beryllium values may be related to geologic features other than mineralization.

NIOBIUM

The only niobium minerals identified in the Charlotte quadrangle are columbite and ixiolite. Some niobium also is present in minerals in which it is not ordinarily a major component, particularly titanium minerals (for example, rutile having 70–>1,000 ppm Nb). Columbite-tantalite is in the pegmatites of the tin-spodumene belt, in the Brown Mountain Granite near the northwestern corner of the quadrangle (pl. 1), and in the Wilson Creek Gneiss west of the Brown Mountain Granite. Ixiolite is present in the Salisbury pluton.

In our mineral separates, columbite is in M.5 fractions and ixiolite mainly in M1 fractions; no niobium mineral has been found in nonmagnetic concentrates. High niobium values are found in all three fractions of concentrates from the northern end of the Brown Mountain pluton, but values are lowest in the NM fraction. High to moderately high niobium values are found within and

west of the Salisbury pluton; values are lowest in the NM fraction, but even these are higher than those in NM fractions from surrounding areas. Niobium values are high in all three fractions from the tin-spodumene belt, and the fraction containing the highest value may differ from one sample site to another. Nonmagnetic fractions from the Inner Piedmont belt are moderately rich in niobium, but much of this niobium is in rutile, ilmenite, and cassiterite that contain as much as 1,000 ppm Nb.

The Charlotte and Carolina slate belts yielded concentrates generally having low niobium contents. Samples taken southeast of the city of Charlotte and west of the Carolina slate belt, however, have moderately high niobium contents in both the NM and M.5 fractions. Niobium in M.5 fractions (fig. 8) is largely in columbite and ilmenite. Samples from the southeast corner of the quadrangle have moderately high niobium contents in the M1 and M.5 fractions, probably derived from recycled old alluvium. In general, the M.5 fractions containing niobium are found most often near places where niobium minerals, particularly columbite, are known to be present, in keeping with the magnetic susceptibilities of the minerals.

Niobium-rich silt samples (Ferguson, 1979) are from a well-defined belt that trends northwestward from the southeastern corner of the quadrangle. Within this belt, the niobium contents rise from common values of about 5 ppm to 35 to 70 ppm over the southern half of the Salisbury pluton (fig. 8); these values are consistent with high niobium values reported in that area by Fullagar and others (1971). Another area has 90 to 190 ppm niobium in silt in Iredell and Alexander Counties and has long been known to be rather weakly mineralized, as indicated by the presence of veins having well-formed quartz crystals, some of which contain rutile fibers, rutile crystals, and hiddenite. Silt elsewhere in the Inner Piedmont and Blue Ridge belts is generally low in niobium except for a few samples from the southern end of the Brown Mountain Granite pluton (fig. 8). Niobium-rich silt samples clustered in the Carolina slate belt, south of Albemarle, N.C., have 40 to 60 ppm Nb. Judging by the presence of other recycled minerals in this part of the area, this niobium may be derived from recycled old sediment and probably has no relationship with small mafic intrusive bodies present there. Two areas having niobium-rich silt south of the city of Charlotte remain unexplained. Niobium from the tin-spodumene belt does not show up very well in silt samples, although the central part of the belt does yield samples that contain 80 to 185 ppm Nb.

Niobium is accompanied by tin and beryllium in most places within the Charlotte quadrangle. The mineral ixiolite, found south of Salisbury, N.C., contains both tin and niobium. In other places, these two metals are in

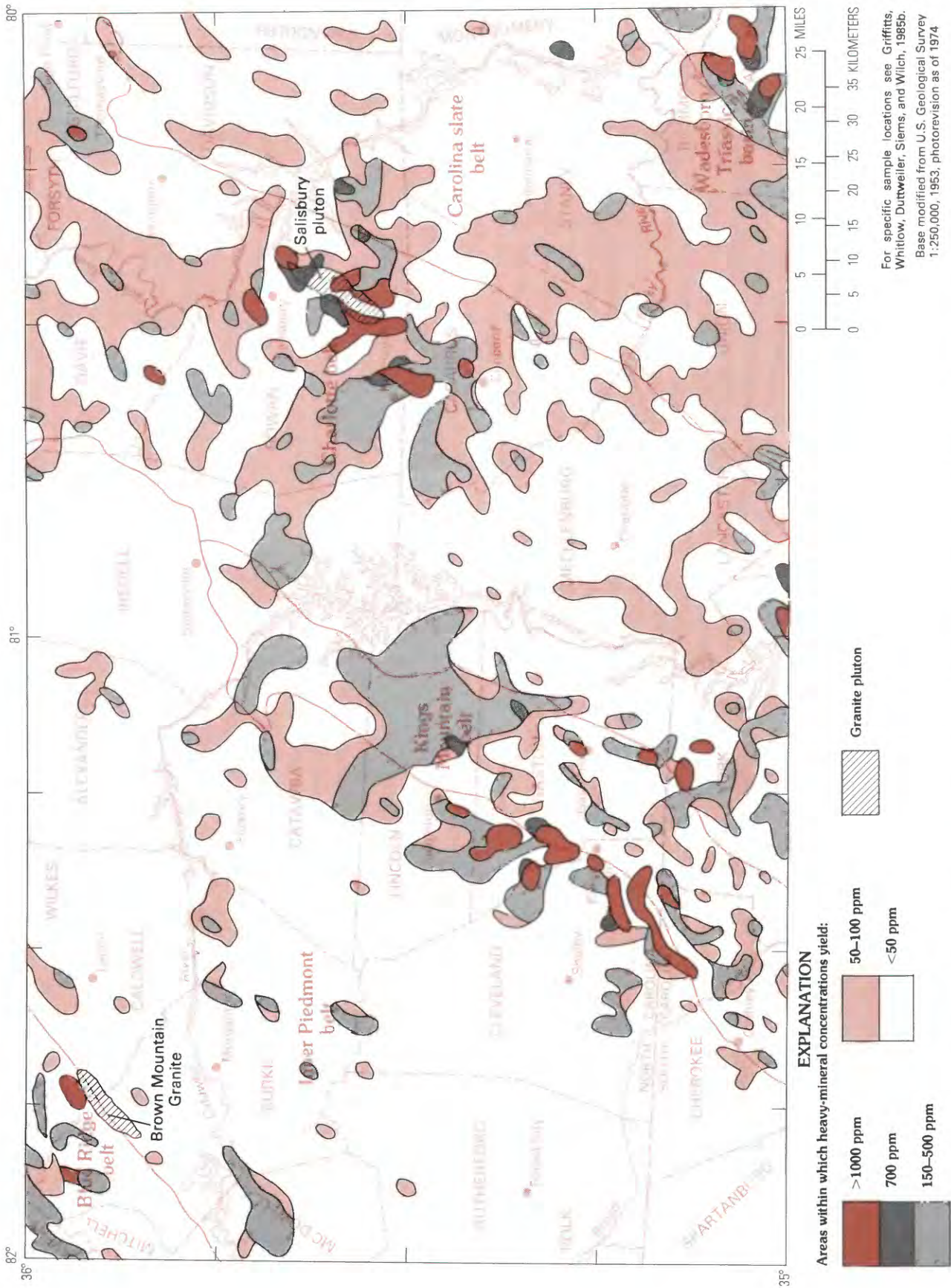


FIGURE 8. — Niobium content of magnetic (M.5) heavy-mineral concentrates in the Charlotte quadrangle.

separate minerals, cassiterite and columbite. For unknown reasons, niobium is associated with cobalt near the Salisbury pluton.

TUNGSTEN

The tungsten minerals known to occur in the Charlotte quadrangle are scheelite and wolframite. Almost all of the scheelite fluoresces bright blue to bluish white in ultraviolet light and thus is easily recognized in the concentrates. Scheelite from a few samples collected over the Wilson Creek Gneiss near the northwestern corner of the quadrangle (pl. 1) fluoresces dull green; its identification was confirmed by X-ray diffraction and optical properties. Wolframite was found in only a few samples, probably because of its superficial similarity to ilmenite and other dark minerals that are dominant in the M.5 fraction in which wolframite occurs. The wolframite grains found are dark metallic gray. Their rather strongly etched or corroded matte crystal faces reflect the known instability of wolframite in areas of warm, humid climate (Raeburn and Milner, 1927, p. 54–56).

Scheelite occurs in the NM fraction and wolframite in the M.5 fraction. Therefore, the map distribution of tungsten in these fractions approximates the distribution of scheelite and wolframite in the Charlotte quadrangle. Because of the ease of determining fluorescent scheelite in concentrates, and because of the high spectrographic threshold of detection for tungsten, the mineralogic determination is more sensitive than the spectrographic determination. Accordingly, the map shows scheelite in many places where tungsten was not detected spectrographically. Nonetheless, there are many nonmagnetic concentrates in which tungsten was detected but scheelite was not. Wolframite would not be present in such nonmagnetic samples, and therefore these concentrates may contain an unidentified and nonfluorescent tungsten mineral derived by weathering, such as anthoinite ($\text{AlWO}_3(\text{OH})_3$).

Twenty-one samples of rutile from concentrates were analyzed spectrographically, and five out of seven rutile samples from the Inner Piedmont were found to contain 100 to 150 ppm W, but tungsten was detected (at 300 ppm) in only 1 of 14 rutile samples from other parts of the quadrangle. Thus, rutile commonly contributes tungsten to NM fractions of concentrates from the Inner Piedmont but does so only rarely elsewhere. The rutile was probably formed and acquired tungsten during amphibolite-facies metamorphism. One sample of spinel from an M1 fraction from the Calahaln 7.5-minute quadrangle (northeast corner at latitude 36°00', longitude 80°37'30") contains 200 ppm W. Other spinels analyzed have no detectable tungsten.

Relatively large amounts of dispersed tungsten in the premetamorphic rocks may have become fixed as scheelite during regional metamorphism, but then areas in the Inner Piedmont where tungsten was detected in silt samples (Ferguson, 1979) should correspond to areas where scheelite occurs in concentrates, and they do not.

The most striking feature of tungsten geochemistry in the Charlotte quadrangle is the antipathy between detectable tungsten in the silt and either scheelite or detectable tungsten in concentrates. In the eastern part of the quadrangle, scheelite is found in gold deposits, but tungsten was detected in silt only east of the gold district located near Charlotte. Scheelite and tungsten-bearing silts are nearly as antithetic in the Inner Piedmont, where neither material is closely associated spatially with mineralized rocks. Scheelite very likely formed from dispersed tungsten during metamorphism, but this does not explain the distribution.

In the eastern part of the Charlotte belt, scheelite and gold are present in the same or nearby NM fractions. Scheelite is also in some auriferous quartz veins; its presence indicates that tungsten and gold mineralizations were related. East of Gaffney, S.C., in the Kings Mountain belt, scheelite also is associated with gold mineralization.

Scheelite is widespread over the tin-bearing southern part of the Cherryville pluton in the Inner Piedmont belt (pl. 1) and immediately south and southwest of the pluton. It is associated with cassiterite and niobium in these areas and probably formed during the widespread tin-niobium-beryllium mineralization of the region. Tungsten in M.5 concentrates occurs mainly near the eastern boundary of the Inner Piedmont in the southwestern part of the quadrangle and probably is related to the tin-niobium-beryllium mineralization.

The scheelite in the rest of the Inner Piedmont belt is not associated with mineralized rocks and is sparse in the known gold district of the South Mountains. Hence, scheelite is not a very useful guide to other nontungsten types of mineralization in these areas.

MOLYBDENUM

The most conspicuous trend in the maps showing distribution of molybdenum in the Charlotte quadrangle is a discontinuous belt that crosses the quadrangle from near the southwestern to the northeastern corners, along which many concentrates contain detectable molybdenum (fig. 9). Northwest of this belt, nearly all samples lack detectable molybdenum. In contrast to the molybdenum-free or molybdenum-poor samples in most of the northwest area, samples clustered in the northwest corner of the quadrangle near thrust faults, the Wilson Creek Gneiss, and the Brown Mountain Granite contain detectable molybdenum (fig. 9).

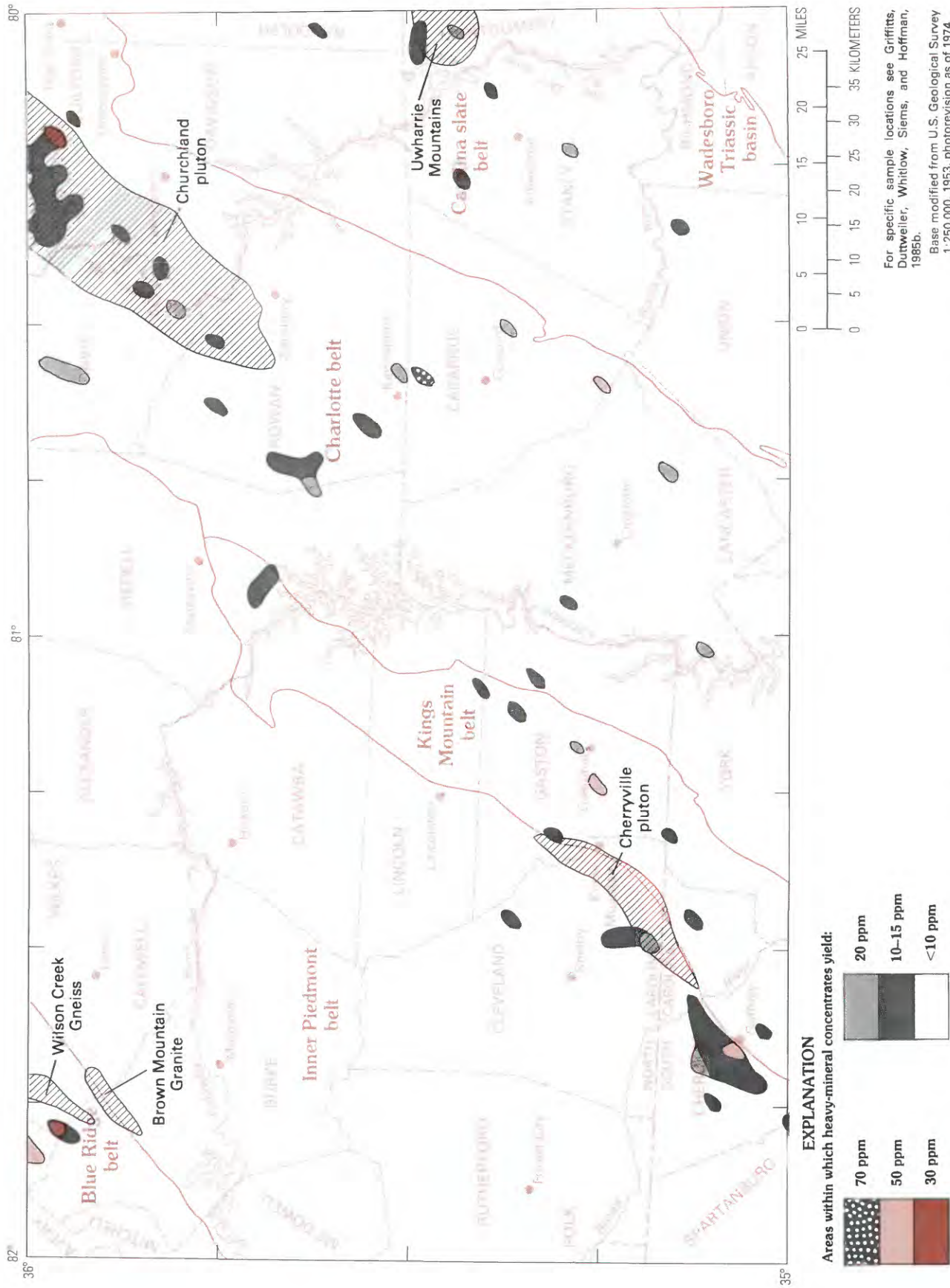


FIGURE 9. — Molybdenum content of nonmagnetic heavy-mineral concentrates in the Charlotte quadrangle.

Molybdenum was detected in NM fractions of samples collected near the Cherryville pluton (fig. 9) in the Inner Piedmont belt, especially near its southern end, but was found in only a few samples from directly over the pluton. Molybdenum also was found in both NM and M1 fractions from over the Churchland pluton in the Charlotte belt near the northeastern corner of the quadrangle and near the northeastern end of the conspicuous trend mentioned above. Molybdenum also was detected in a number of NM and M1 fractions of other samples from the Charlotte belt and in M1 fractions from the Kings Mountain belt. A few NM fractions from streams that drain rocks of the Carolina slate belt, particularly the Flat Swamp Member of the Cid Formation (pl. 1), also contain detectable molybdenum.

Eighteen molybdenum-rich M1 concentrates from the Charlotte belt southwest of the Churchland pluton were collected over or adjacent to silicic intrusive bodies. These samples indicate hydrothermal mineralization related to the small intrusive bodies. The M1 fractions of two such samples at or near the Newell copper-molybdenum prospect (Worthington and Lutz, 1975) contain 10 to 15 ppm Mo, as do two M.5 fractions.

Molybdenum was detected in many silt samples from the Carolina slate belt (Ferguson, 1979), but values exceed 5 ppm Mo in only 15 percent of the samples. Molybdenum-bearing silt samples also are present in the gold-producing area of the Charlotte belt southeast of the city of Charlotte, and in the gold belt of the Charlotte belt southeast of the Uwharrie Mountains (fig. 9). Molybdenum also occurs in silt in the Inner Piedmont belt near Statesville, N.C., associated with high beryllium values. The molybdenum-beryllium association may reflect mineralized bedrock in the sample area. The area of the Cherryville pluton yielded only a few samples of silt containing 5 ppm or more molybdenum. The stanniferous area west of the pluton, however, yielded many silt samples containing 5 ppm Mo and a few containing 10 ppm Mo. This molybdenum may be related to the tin mineralization of that area, and scattered molybdenum-bearing samples may overlie buried tin-rich plutonic rocks.

TITANIUM MINERALS

Stream sediments in the Charlotte quadrangle contain all five of the most common titanium minerals: ilmenite, rutile, anatase, brookite, and sphene. Only ilmenite and rutile are truly widespread, being found in most samples. Ilmenite is largely in the M.5 fraction, whereas the other titanium minerals are in the NM fraction.

Ilmenite is by far the most abundant titanium mineral. It is especially prominent in the Charlotte belt, where it may constitute two-thirds of a crude panned sample. It is

derived from mafic rocks that are particularly abundant in this belt. Where the stream sediment is derived largely from gabbro or other mafic rock, the ilmenite is accompanied by abundant apatite, sphene, and dark ferromagnesian minerals. In the Inner Piedmont belt, ilmenite is associated with abundant sillimanite, garnet, zircon, and monazite, all derived mainly from schist, and to a lesser extent from granitic rocks.

In most places, ilmenite is in irregular black particles without crystal faces. Euhedral crystals of ilmenite are very rare except in the Carolina slate belt. Even there fresh ilmenite crystals are not common; most are tablets having dominant basal pinacoids that have small prism and rhombohedral faces. Most are partly to completely altered to fine-grained rutile (leucoxene). Many of the larger grains in most parts of the quadrangle are laminated, most commonly by twinning and less commonly by interlayering with other minerals.

Rutile is present in widespread monocrystalline grains and fragments of prisms typically colored yellow, reddish, or pale brown to black. It is also in microcrystalline "leucoxene" (light-gray to tan spherules and hexagonal plates pseudomorphous after ilmenite³) in greenschist-facies rocks of the Carolina slate belt. The microcrystalline rutile, we conclude, formed during progressive metamorphism to greenschist facies. Monocrystalline rutile grains are coarsest west of the Charlotte belt. The rutile grains in the Carolina slate belt tend to be small, but well-rounded coarse grains are plentiful in the southeastern part of the quadrangle, where they have been washed into modern streams from older sediments. Rutile has been derived from most kinds of rock in the Inner Piedmont and Kings Mountain belts. Especially large and well-developed crystals are present in kyanitic quartzites of southern Lincoln and Gaston Counties, N.C., and in dikes and veins in mica schist and gneiss of the Hiddenite area, Iredell County, N.C. (fig. 7).

Small bipyramids of anatase are widespread but rarely constitute more than a few percent of the heavy mineral concentrates. The mineral typically is bright blue or black. It is common in or near areas that contain clinozoisite, so it may generally be a product of rather low-grade metamorphism. The main exception to this association with clinozoisite is in the north-central part of the quadrangle, near Hiddenite. There anatase crystals are larger than in most other parts of the quadrangle and may have formed during postmetamorphic hydrothermal activity that also formed quartz crystals, including rutiled quartz, and coarse rutile crystals. Anatase generally is coarser grained in the Inner Piedmont, Blue

³Such "leucoxene" consistently yields rutile X-ray patterns. Spotty diffraction patterns are produced by single unpowdered pseudomorphs, indicating substantial but incomplete parallel alignment of the component crystallites.

Ridge, and Kings Mountain belts than it is farther east. An X-ray diffraction study showed anatase accompanied by rutile in yellow crusts of leucosene on sphene crystals from the Charlotte belt. The crusts probably formed by weathering.

Some grains of brookite are found in the NM fraction of concentrates mainly in or near areas yielding clinozoisite. Most grains are small striated tablets, mainly colorless, but also mottled brown or blue.

COBALT

Cobalt, detected by spectrograph, is widespread in the M.5 fraction and common in the NM fraction of samples from the Charlotte quadrangle. No cobalt minerals were recognized in our investigations, and it is inferred that the cobalt in these samples is in manganese-oxide minerals. Cobalt is particularly widespread in the Carolina slate belt, where it may be related to minor northeast-trending faults. In these areas and also in others west of the slate belt, cobalt is so commonly associated with gold as to indicate that both were involved in the same episodes of mineralization. Cobalt is not closely associated with mafic rocks in the Charlotte quadrangle, as is indicated by the high cobalt contents of magnesium-poor M.5 concentrates (fig. 10). Clusters of cobalt-rich samples are distributed roughly along a line extending west-northwest from a point near the southeastern corner of the quadrangle to the vicinity of Charlotte, N.C. An unusually large group of samples collected over and adjacent to the Salisbury pluton in the Charlotte belt contains high cobalt values, associated with gold as in most other places in the quadrangle but also accompanied by niobium and tin. The pluton is the source of the niobium and tin, but the sources of the cobalt and gold are unknown. Cobalt-rich samples also occur in the Kings Mountain belt near Blacksburg, S.C., where they contain gold and zinc in addition to cobalt. These cobalt concentrations may be related to gold-quartz vein deposits, or gossans and other iron deposits of the Blacksburg area.

The cobalt content of minus 100-mesh sediment (Ferguson, 1979) is rather high in places in the eastern part of the Charlotte belt and the eastern and northern parts of the Carolina belt. Unlike the cobalt in the M.5 fraction of concentrates, high cobalt values in silt samples generally are found between, not in, areas of gold mineralization.

LITHIUM

Spodumene, by far the most abundant lithium mineral in the Charlotte quadrangle, occurs in the pegmatites of the tin-spodumene belt (Kesler, 1942) along the southeastern side of the Inner Piedmont, particularly near Kings Mountain, N.C., and north of this belt at Hiddenite, N.C. (fig. 7). The only other widespread lithium

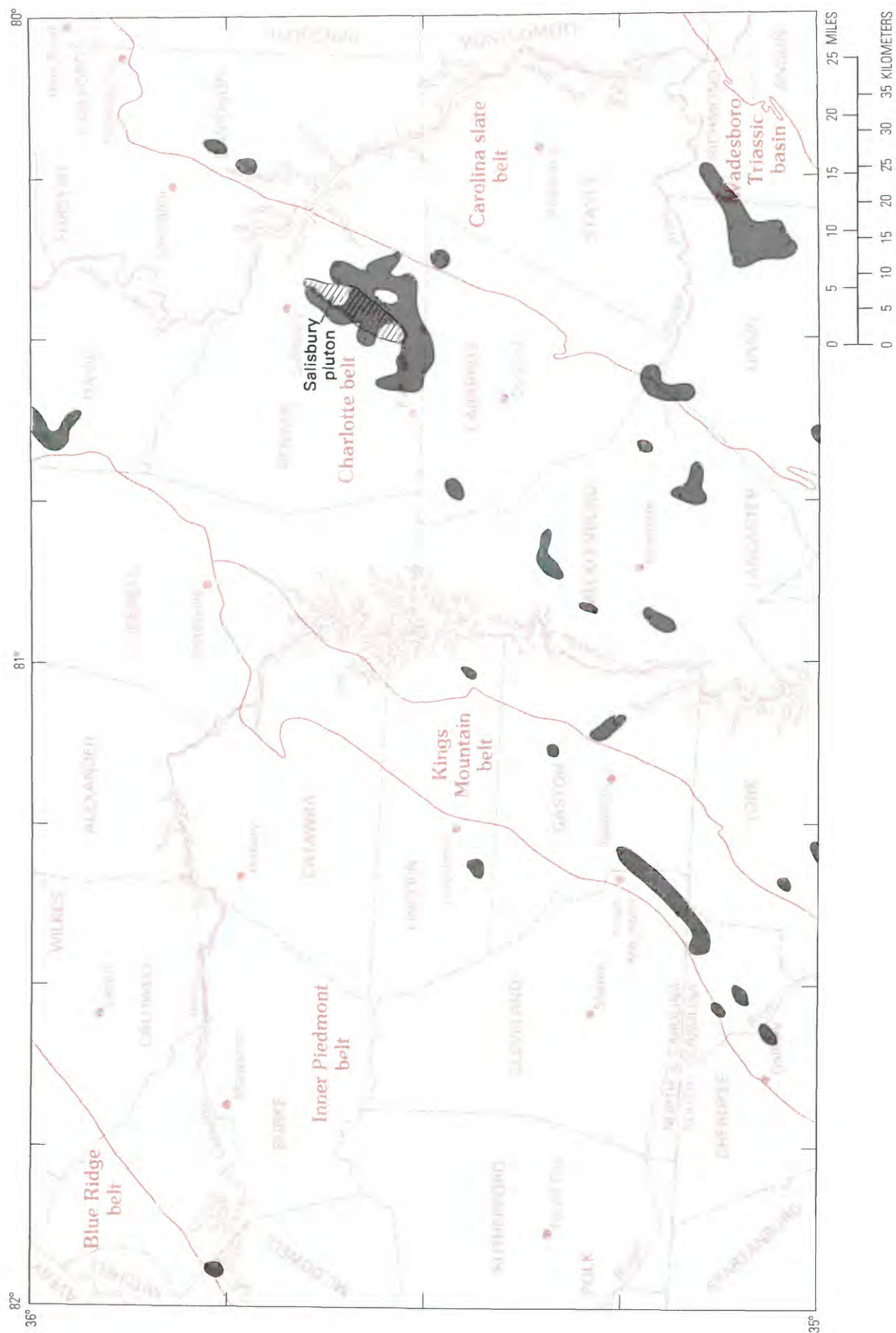
mineral, holmquistite, is in amphibolite in the lithium districts. The tin-spodumene belt is the most prominent feature on the geochemical map for lithium (fig. 11). All silt samples from the quadrangle that contain 100 ppm or more lithium are from this belt; many contain 20 to 99 ppm Li, and none contain less than 20 ppm Li (Ferguson, 1979). A most unexpected finding of the geochemical survey is the moderately high lithium contents of silt samples taken as far as 10 mi (16 km) north of the apparent northeast end of the tin-spodumene belt east of Lincolnton. Confirmation that rocks in this area were mineralized is provided by high contents of beryllium, tin, and bismuth in NM fractions of concentrates (all are common associates of lithium in other districts). The nature of the bedrock source of these metals is unknown, but it probably is not pegmatite, which is scarce or absent.

Lithium-rich silt (20 to 99 ppm Li) also extends beyond the southern part of the tin-spodumene belt, where it spreads westward over the altered southern half of the Cherryville pluton (fig. 11). There, too, the concentrates have high contents of tin, beryllium, and bismuth. The source of the high metal values in samples may be quartz-mica veins and pods in the altered granitic rock. Silt has moderate contents of lithium for about 10 mi (16 km) west of the southern part of the Cherryville pluton, and many concentrates from this area are rich in tin. Greisen, found as float in this area, may be the source of the tin and lithium. Lithium-rich silts within the Inner Piedmont extend northward to the vicinity of the Catawba River; concentrate samples in this area have high beryllium values but no tin. Of the three identified stanniferous granite plutons in the Charlotte quadrangle (the Cherryville, the Brown Mountain, and the Salisbury) only the Cherryville has lithium-rich silts associated with it.

Silts in an area between the Salisbury pluton and the Wadesboro Triassic basin at the southeastern corner of the quadrangle contain 20 to 99 ppm Li, and concentrates from the same area are moderately rich in tin. The area is not known to be mineralized, but small amounts of gold, copper, and zinc are widespread in the stream sediments. Silts commonly contain 20 to 99 ppm Li in the southern part of the Carolina slate belt and 11 to 20 ppm Li farther north in the slate belt. These values are rather low but are above those of much of the quadrangle.

BARIUM

Barite was found long ago in the Kings Mountain belt and has been mined at Kings Creek mine, S.C. (see section on barite in the Kings Mountain belt by Horton).



For specific sample locations see Griffiths, Whitlow, Siems, Duttweller, and Hoffman, 1985.

Base modified from U.S. Geological Survey 1:250,000, 1953, photorevision as of 1974

FIGURE 10. — Areas of the Charlotte quadrangle from which magnetic (M.5) heavy-mineral concentrates yield 200 ppm or more Co and less than 0.5 weight percent Mg (shaded areas).

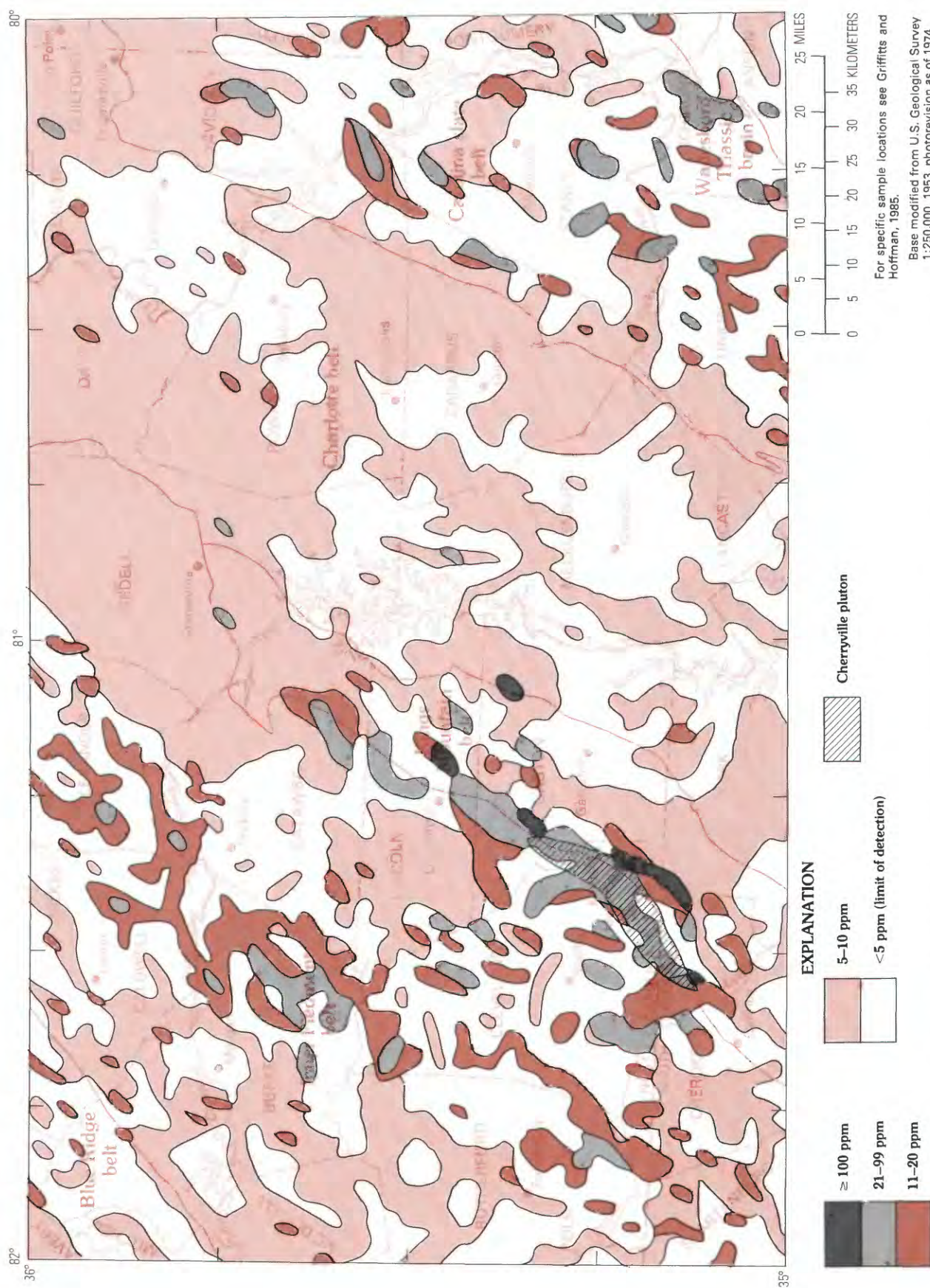


FIGURE 11.—Areas of the Charlotte quadrangle in which silt samples contain measurable concentrations of lithium.

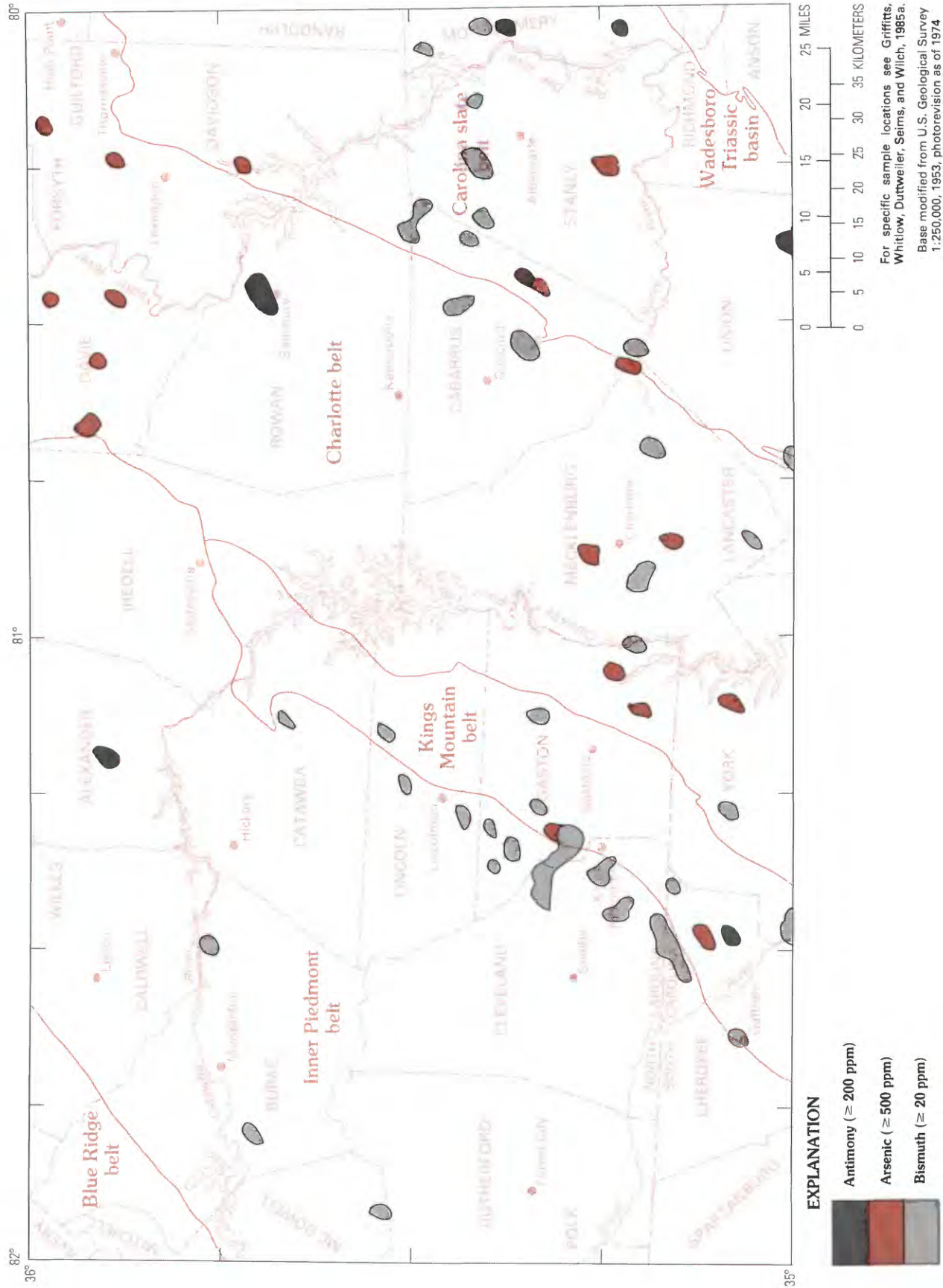


FIGURE 12.—Areas of the Charlotte quadrangle from which nonmagnetic heavy-mineral concentrates contain detectable antimony, arsenic, and bismuth.

It has also been found in eastern and central Cabarrus County, mainly in the Charlotte belt (Wilson and McKenzie, 1978). The barite in the Kings Mountain belt is in pods with minor galena and other sulfides in fractured pyroclastic rock, whereas the barite in Cabarrus County is associated with gold, scheelite, and several copper minerals in veins.

Three features are prominent on the barium geochemical map of the Charlotte quadrangle. The most conspicuous is a discontinuous belt of barium-rich silts that extends diagonally across structures and lithologic units from near the northeastern to the southwestern corners of the quadrangle. This belt of barium silts yields barite-bearing concentrates only near its southwestern end. Therefore, the barium in the silts of this belt is not generally related to barite mineralization. Less conspicuous are two clusters of barite-rich concentrates, including the Kings Creek barite-producing area in the Kings Mountain belt and an area along the eastern edge of the Charlotte belt in which barite is in metalliferous veins. Geochemical data indicate that the barite-bearing zone represented by the first-mentioned cluster extends many kilometers northeast of the northernmost barite mine in the belt (the Lawton mine on the east side of Crowders Mountain) (see section "Barite in quartz-sericite schist and schistose pyroclastic rock of the Kings Mountain belt"). The geochemical data indicate that barite mineralization may be more widespread than the known distribution of barite along the eastern edge of the Charlotte belt.

ANTIMONY, ARSENIC, BISMUTH, AND CADMIUM

Antimony, arsenic, bismuth, and cadmium are known common accessory elements in base- and precious-metal deposits in many areas, so they can be helpful in identifying mineralized districts and predicting mineral assemblages that may be in undiscovered deposits. They were detected in many of our nonmagnetic concentrates.

Antimony was found in nine samples, mainly from gold-bearing areas of the Carolina slate belt (fig. 12), but only two of the antimony-bearing samples also contain detectable gold. Arsenic was detected in 14 samples in the southern half of the quadrangle, from a broad mineralized area that contains many gold prospects, although gold was found in only 6 of the arsenic-bearing samples. Other metals that are less commonly associated with arsenic are copper, found in two arsenical samples; zinc, found in three; and bismuth and cadmium, each found in one sample. Thus, antimony and arsenic help to delimit gold-rich areas. There is no evidence of contamination by hardened lead shot or arsenical insecticides.

Cadmium, too, occurs in some precious-metal districts in the Carolina slate belt and near the southeastern edge of the Charlotte belt. Cadmium is prominent in the

northeastern corner of the quadrangle, where a cluster of cadmium-bearing samples is associated with base metals. Every zinc-rich sample from this area contains cadmium.

Bismuth is markedly localized in the tin-spodumene belt and is closely associated there with tin. Of 40 samples in that belt containing bismuth, 31 also contain at least 1,000 ppm Sn, 3 have 500 to 700 ppm Sn, 2 have 20 to 100 ppm Sn; and only 4 contain less than 20 ppm Sn. No bismuth mineral has been reported from the spodumene deposits, so the bismuth may be a component of cassiterite or of a bismuth mineral that is so weathered it has not been recognized. Tin also is present in four of the six bismuth-bearing samples from the Inner Piedmont belt west of the tin-spodumene belt. Bismuth has not been found in the tin districts related to the granite plutons in the northwestern part of the quadrangle and south of Salisbury and was not detected in other mineralized areas in the quadrangle.

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CRITERIA FOR ASSESSMENT OF MINERAL-RESOURCE POTENTIAL

By JACOB E. GAIR

DEFINITION OF MINERAL-RESOURCE POTENTIAL

What is meant by mineral-resource potential? In considering mineral-resource potential, we are concerned with the probability of mineral occurrence, particularly mineral occurrence of sufficient size and grade (quality) to constitute an economic resource. An assessment of mineral-resource potential evaluates the possibility that such resources exist in an area, and it may include more or less quantitative measures of the probability of mineral occurrence. In the Charlotte quadrangle, we have not attempted to determine amounts and grades of resources. The various tests applied are based on data acquired during the CUSMAP study. The data are major indicators of the potential for mineral resources but generally are not adequate or appropriate for evaluating other factors critical for the development of mineral resources such as specific volume and grade of deposits, problems of extraction (engineering and metallurgical problems), and the requirements of environmental protection. Hence, an assessment of high potential for tin resources in an area states that it is highly likely that tin deposits are present but does not necessarily state that such deposits are large or of high quality or that the deposits will satisfy other requirements for successful development.

One factor in the assessment that is not entirely an aspect of mineral occurrence is a comparison of the size of a deposit with those now being exploited elsewhere. If we postulate the occurrence of deposits, but such deposits are probably orders of magnitude smaller than deposits widely available elsewhere, we will discount the mineral-resource potential of such small mineral occurrences. A good example of this situation in the Charlotte quadrangle is provided by iron deposits. Small iron deposits were worked in the past, and the probability of occurrence of additional small iron deposits is high, but the mineral-resource potential for iron in the quadrangle is considered to be low to nil because the size of the deposits and the comparative volume of the commodity are small.

RECOGNITION CRITERIA

Various criteria can be used to assess the potential for a mineral resource. A mineral deposit that is not exposed or otherwise obvious (which is now true of almost all undiscovered deposits) may be tentatively identified and crudely assessed by clues derived from inherent descriptive qualities of the deposit, such as unique host rock, mineral and chemical content, or physical properties like magnetism or high density (specific gravity). These criteria are only a portion of the possible information about a deposit. Some or all of the recognition criteria may also be applicable to ordinary, nonmineralized or slightly mineralized rock; therefore, recognition criteria do not prove the existence of a mineral deposit. However, without the presence and discovery of such criteria there is little likelihood of finding a concealed deposit and virtually no way of assessing mineral-resource potential.

Recognition criteria are considered to be three types: diagnostic, permissive, and negative. Diagnostic (required) criteria are those that are present in nearly all known deposits of a given type; favorable host rock and known mineral occurrence are diagnostic criteria for potential resources. There should be a favorable host rock present, or at least an absence of unfavorable rock, for a given type of deposit to exist in an area. Failure to identify favorable host rock severely limits the possibility that a given type of deposit exists in an area and precludes assessing its resource potential. Without favorable host rock, resource potential can be identified only at the actual locations of known mineral occurrence or anomalous geochemical samples. The presence of favorable host rocks (containing deposits or geochemical anomalies somewhere in such rocks) indicates a possibility of mineral deposits anywhere else in these rocks; for example, the possibility of gold any place where there is volcanic-sedimentary rock of the Carolina slate belt or vein quartz.

Permissive criteria commonly, but not necessarily, suggest the presence of a given deposit type. Such criteria strengthen the possibility that a deposit of a specified type exists, but their absence does not rule out such a deposit. For example, in a suitable volcanic terrane, a geochemical anomaly for copper, lead, and (or)

zinc in soil may indicate the presence of a base-metal massive-sulfide deposit. However, unpredictable factors of weathering or ground-water circulation can prevent an anomalous concentration of these elements in the soil; only small amounts may be leached from deposits or they may be largely flushed out of the soil. Therefore, the absence of a geochemical anomaly is not diagnostic. The presence of more than one permissive criterion is generally thought to be a more favorable sign than a single permissive criterion. However, the gradations in potential that may be established by the exercise of combining varying numbers of permissive criteria are considered to be too slight or subtle, or to have too many unexplained causes, to provide meaningful measures of potential. On the other hand, combinations of diagnostic and permissive criteria as used in this report provide an adequate basis for defining major degrees of mineral-resource potential.

The proven absence of a diagnostic criterion can, in effect, be a negative criterion, such as where a required type of host rock is known not to be present. Gold, for example, is associated with several types of host rock (as in the list of mineral-deposit types in the next section) but pegmatite is not among them. Therefore, in areas of pegmatite, one would not expect a potential for gold.

DEGREES OF RESOURCE POTENTIAL

Our data generally do not enable us to make quantitative estimates of mineral-resource potential, so we choose to express potential in the qualitative terms of high, moderate, low, and nil. We define these terms in accordance with factors that have been determined during the CUSMAP survey. These factors are favorable formations or types of rock, mineralization, geochemical (trace-element) and heavy-mineral anomalies, geophysical patterns, and various combinations of these factors (fig. 13). In figure 13, the combinations of these factors and the mineral-resource potentials inferred from them are (1) favorable geology plus known mineral occurrence (evidence of high resource potential); (2) a geochemical or heavy-mineral anomaly plus favorable geology (evidence of moderate resource potential); and (3) a geochemical or heavy-mineral anomaly plus known mineral occurrence such as a mine or prospect (evidence of moderate resource potential).

The various factors, each taken alone, can be considered at best as only permissive for the existence of mineral resources and are therefore considered to indicate only low potential. A geophysical anomaly alone is, at best, evidence of low resource potential, but in most instances it is too inconclusive or too indirectly associated with resource potential to be useful and is not considered to provide significant evidence of potential. Other factors

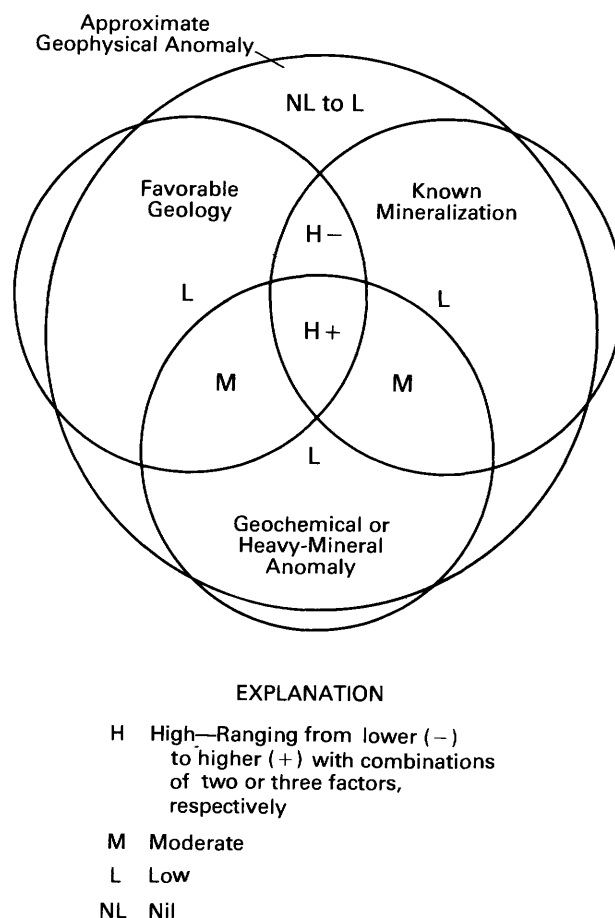


FIGURE 13.—Schematic diagram for estimating mineral-resource potential.

(more detailed descriptive data) can be associated with the various types of deposit, but generally such data are not available from the CUSMAP study of the Charlotte quadrangle, so they have had little or no influence on our estimates of mineral-resource potential beyond the confines of known deposits.

These criteria have also been used in the preparation of mineral-resource potential maps for most of the commodity minerals known in the quadrangle (see Gair and others, 1986, for a brief description and listing of the mineral-resource potential maps; also see other references at the end of this section). Some maps in this series also evaluate the mineral-resource potential for deposit types not known to constitute resources in the quadrangle, largely or entirely on the basis of geochemical data (which, by the criteria used in this study, restricts to "low" or "moderate" the maximum resource potential that can be determined).

Favorable geology is the most important overall condition that needs to be satisfied to identify an area as having mineral-resource potential. Favorable geology

encompasses all aspects of geologic setting; the type of bedrock, however, carries far more weight than other geologic features. Favorable geology cannot be determined in an abstract sense but must be deduced from associations of mineralization with specific types of rock or other geologic features such as faults. The associations utilized may occur in or near an area under consideration, such as the Charlotte quadrangle, or elsewhere in the world. Determining local favorability on the basis of a distant association, however, results in a much more tenuous conclusion than is derived from an association of geology and mineralization or geochemistry within the region being assessed. Favorable geology thus can be only as well established as the mineral or chemical data used to identify the favorable feature. These data generally constitute "spots" on the map, and the only reliable basis for projecting resource potential away from or between such "spots" is a favorable geologic feature.

At a map scale of 1:250,000, it is quite possible—even likely—that a map unit may be generally favorable for a given type of mineral occurrence but that within the unit there may be specific beds that are unlikely host rocks. Therefore, generalizations about the mineral-resource potential of a map unit may be subject to local variations within the unit, just as lithologies may vary. Many types of deposits are small and occur in specific host rocks of dimensions that are too small to show on the map; therefore, it is impractical in many places to show small gradations of mineral-resource potential that correlate with unmapped small-scale variations in geology. In general, at 1:250,000, the mapped geology can be known only to be broadly favorable, indifferent, or definitely unfavorable for the occurrence of specific mineral resources.

The next most important factor indicating resource potential is the actual presence of mineral occurrences. The presence of known mineral occurrences, particularly small ones, does not automatically constitute mineral-resource potential. Mineral occurrences have a strong positive influence on the evaluation of resource potential because actual mineral occurrences support the possibility of still more (and bigger) occurrences. This is especially true where there are sizable unexplored extensions of rock units containing known occurrences. The absence of known mineral occurrences in parts of a rock formation that have occurrences elsewhere in the formation is not considered very significant, because it may reflect only insufficient exploration; therefore, a local absence of mineral occurrences has only a small negative influence on the evaluation of mineral-resource potential. If no mineral occurrences are known anywhere in a formation, however, there is little basis for predicting future discoveries in that formation. A determination of mineral-resource potential then has to be based on other consid-

erations such as geochemical anomalies in the formation or mineralization occurring in similar rocks elsewhere.

Resource potential based on the presence of known mineral occurrences may range from high to nil. Potential is considered high near known occurrences that are located in a favorable formation. Potential decreases to low within the favorable formation at distances away from the known mineral occurrences. Isolated, small mineral occurrences not associated with any identifiable favorable formation are accorded low potential at best. Zones of higher potential are extended farther along the strike of a formation or structure than perpendicular to the strike. If there is widespread random or irregular distribution of mineralization in a favorable formation, the entire formation can be designated as a zone of high potential, or high to moderate potential, depending on the spacing or ubiquity of mineralization. Absence of known mineralization in a formation provides little basis for assigning a mineral-resource potential, and if other factors such as geochemical anomalies also are absent, the potential of a formation is considered nil; that is, it is not be designated as a favorable formation.

Geochemical and heavy-mineral anomalies, combined with favorable geology or known mineral occurrences, are the bases for designating moderate potential. The identification of anomalies requires knowledge of cut-off levels of trace elements or heavy minerals between background amounts and the anomalies. The levels of trace elements and heavy minerals used in the present study are based on general experience and data acquired during the study. In assigning resource potential, it also has been important to know what types of mineralization are suggested by given anomalies. Contamination or other nonsignificant sources of an anomaly, such as lead in thorium or lead shot (Griffitts and others, 1985), also need to be ruled out.

The most obvious associations between geochemical or heavy-mineral anomalies and mineralization are direct indications, such as copper anomalies for copper mineralization, tin anomalies for tin mineralization, or barite, gold, or cassiterite heavy-mineral anomalies in stream sediments for barite, gold, or tin mineralization. Even with direct associations between anomalies and their mineral source, we have no guarantee of resources. Mineralization may be in the form of very small bodies, or only slightly mineralized rock. The wide ranges in intensity of mineralization that can produce anomalies, especially smaller or weaker anomalies, and uncertainty in many situations as to the source of a geochemical anomaly limit the value of anomalies as guides to or measures of mineral-resource potential.

Geochemical anomalies alone, except for rare huge anomalies, are considered indicative of low potential at

best and even in combination with favorable geology are not as supportive of mineral-resource potential as actual observed mineralization. Therefore, anomalies plus favorable geology or anomalies plus mineral occurrence are assigned only moderate potential. Geochemical or heavy-mineral anomalies near known mineral occurrences in a formation reflect the obvious mineralization and reveal little more about mineral-resource potential than is already known. In these cases, the mineral-resource potential is considered high, grading to moderate away from the known mineral occurrences.

In setting up categories of mineral-resource potential and applying them to different areas of the map, a question inevitably faced is how far one may extrapolate the known data into the "unknown" to extend a category of mineral-resource potential. A designation of low potential, dependent only on the presence of a favorable lithostratigraphic unit, can be extended to the boundaries (contacts) of the unit. On the other hand, areas of high or moderate potential, based on spot locations for mineral occurrences or geochemical data, can generally be extended away from the data sites only on an arbitrary or intuitive basis. In the Charlotte quadrangle, areas of moderate or high potential are defined by extrapolating distances from data sites that are consistent with the maximum dimensions of the known mineralized districts. For example, if a known district extends along strike for 5 km and is 0.25 km wide, an area of potential resources should not be projected more than these distances from data sites.

There can be no assurance that mineralization in an area will produce geochemical or heavy-mineral anomalies in soil or stream sediments, particularly where mineralization exists below the reach of weathering or erosion. Also, primary minerals may be resistant to chemical weathering and prevent significant dispersal of metallic elements in soil or streams, or the dispersal of elements by ground water and streams may weaken anomalies or prevent them from forming. For these reasons, an absence of anomalies is not considered particularly unfavorable. Resource potential that is considered low on the basis of factors other than geochemical anomalies may be downgraded to nil because of an absence of anomalies, but otherwise moderate or high potentials probably should not be downgraded to low or moderate, respectively, because of an absence of geochemical anomalies.

Placers or other secondary mineral concentrations in the weathering and erosion cycle, such as in colluvium and saprolite, are evaluated on a different basis from bedrock deposits. Recognition of a placer, or of a colluvial or saprolitic mineral-bearing concentration, establishes at once the dual requirement for high resource potential: favorable "host rock" or "formation" and the occurrence

of "mineralization." Therefore, the immediate vicinity of particulate gold concentrations in alluvium, for example, is considered an area of high potential for placer gold resources. The potential grades to low at arbitrarily selected distances from the gold occurrences, generally a few kilometers upstream and a fraction of a kilometer downstream from a sample site (Gair and D'Agostino, 1986). The greater distance upstream is based on the greater certainty that minerals will be present upstream from a sample site.

The above considerations have been primarily about favorable indications of mineral-resource potential. For most commodities, however, large areas of the map will be designated as areas of essentially unknown resource potential (see mineral-resource potential maps for the Charlotte quadrangle, briefly discussed by Gair and others (1986) and also listed in the references at the end of this section). These areas, uncolored on most of the resource-potential maps of the quadrangle, represent either areas of insufficient data or areas in which unfavorable information definitely counters the possibility that mineral resources of a specific type are present. An example of a negative assessment based on an unfavorable association is the assignment of no potential for tin resources to areas of gabbroic and ultramafic rocks. The situations of no data and unfavorable data have been distinguished on the resource-potential maps for copper and tin (Gair and Griffiths, 1986; Gair, 1986); the blank areas on the other resource-potential maps are mainly areas of unknown or no evident potential, but undoubtedly smaller areas that actually have no potential are included within those broad blank areas. A mere absence of data may not preclude the ultimate discovery of mineral resources, but, where the bedrock is unfavorable for specified deposit types, there is no likelihood of ultimate discovery of corresponding resources.

The criteria used to determine mineral-resource potential are too broad to ensure uniform weighting of a stated potential from one area or lithotectonic belt to another in the Charlotte quadrangle. For example, the combined criteria may indicate moderate potentials for zinc in parts of the Carolina slate belt and the Kings Mountain belt. But is the potential in one area equivalent to the potential in the other area? The production history for zinc in each area can be a basis for giving "moderate" potential more weight in one area than in the other area. Production of zinc from a number of deposits in the Carolina slate belt but from only one place in the Kings Mountain belt suggests that favorable designations of resource potential ("moderate," or either of the other two designations) may be more valid for zinc in the Carolina slate belt than in the Kings Mountain belt. The production data (see section on mineral production by DeYoung and Lee) have not been integrated into the

assessments of mineral-resource potential presented in the following sections, but the suggestion is made here that the designated resource potentials (Gair, 1986; Gair and Griffiths, 1986; Horton, 1987) be weighted more heavily in areas of known mineral production than in areas without production. To some extent, such weighting is already accomplished on the maps where the designated resource potential is based in part on known mineral occurrence represented by mine sites. Weighting based on production data can be ordered in accordance with the order of production volume, county by county.

The subsequent sections of this report contain descriptions of the different deposit types (models) of the quadrangle and a brief resource assessment of each, data permitting.

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POLYMETALLIC BASE-METAL, PRECIOUS-METAL, AND PYRITIC STRATABOUND DEPOSITS IN VOLCANIC-SEDIMENTARY HOST ROCKS OF THE CAROLINA SLATE BELT

By JACOB E. GAIR

GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

Stratabound deposits of base-metal sulfides, pyrite, and the precious metals (gold and silver) in volcanic rocks and related argillaceous sedimentary rocks are numerous and widespread within the Carolina slate belt (fig. 14), but most individual deposits are quite small. Many of these deposits were discovered in the search for gold and were worked principally or entirely for gold throughout their history. Some of the earliest gold produced in the United States came from these deposits, and total gold production was large by national standards until the middle of the 19th century. Total production of base metals and of sulfur from pyrite has been small by national standards.

At a number of places, gold was recovered from weathered rock (probably originating in disseminated and massive pyrite) and from quartz veins and pods associated with weathered stratabound, disseminated-and massive-sulfide deposits in which quartz and sulfide deposits are conformable with layers of volcanic and sedimentary rocks. Some of these deposits also yielded supergene concentrations of copper and lead. As these materials were mined to the base of the weathered zone, primary sulfide mineralization was encountered and locally was rich enough to be mined for base metals, principally copper. The major deposits of this type were in the Gold Hill district, Rowan County; the Cid district, Davidson County; and at the Silver Hill, Conrad Hill, and Emmons mines, Davidson County (table 2).

Apparently, very rich ore containing a reported (approximate) 97 oz/ton gold was mined near the surface at the Reed mine, Cabarrus County, between 1831 and 1835, but the main production from this property was from placers. Subsequent deeper lode mining at the Reed mine failed to bear out the reported grades of the earlier mining.

DESCRIPTIVE MODEL

Size and grade of sulfide lenses, silicified and (or) carbonatized zones, and other areas of mineral concentration

Length: Mainly 100 to 200 m or less; a few are about 500 m.

Width: Commonly from less than 1 to 5 m; mineralized zones as much as 15 m wide. One deposit, at the Russell mine, Montgomery County, has six mineralized zones of sulfide and carbonate in chlorite-sericite-carbonate rock (T.L. Klein, 1984, oral commun.), distributed across a belt about 600 m wide.

Depth: Most deposits mined to more than 75 m depth; a few mined to 125 to 200 m; the deepest mining was to 250 m. Ultimate depth of mineralization unknown.

Volume (tonnage): Individual known deposits vary from a few hundred to about 250,000 tons of sulfide ore. Aggregate tonnage of a number of deposits within the Gold Hill district may approach 1.5 million.

Grades:

Deposits dominated by pyrite and chalcopyrite (Gold Hill type):

Copper—As much as 4 percent (ore grade = 1.5 to 4 percent).

Lead—Trace.

Zinc—Trace.

Gold—Average different deposits, 0.1 to 0.3 oz/ton, but local "spots" richer, up to about 18 to 19 oz/ton.

Silver—Trace to 1 to 2 oz/ton.

Deposits dominated by sphalerite and galena (Silver Hill type)

Copper—0.3 to 1 percent.

Lead—10 to 19.5 percent.

Zinc—25 to 40 percent.

Gold—In mixed sulfide ore, 0.2 to 0.6 oz/ton. In local zones of pyritic gold ore, 9 to 24.5 oz/ton.

Silver—In low-grade zones, 6 to 30 oz/ton.¹ In high-grade zones, 95 to 200 oz/ton.¹

Lithology of host rocks

Metarhyolite flows and tuffs; meta-andesite flows and tuffs; argillite; quartz-sericite and chlorite-sericite phyllites; silicified varieties of these rocks.

¹Calculated from reported dollar values per ton, assuming silver price of \$0.60/troy oz (1898 approximately).

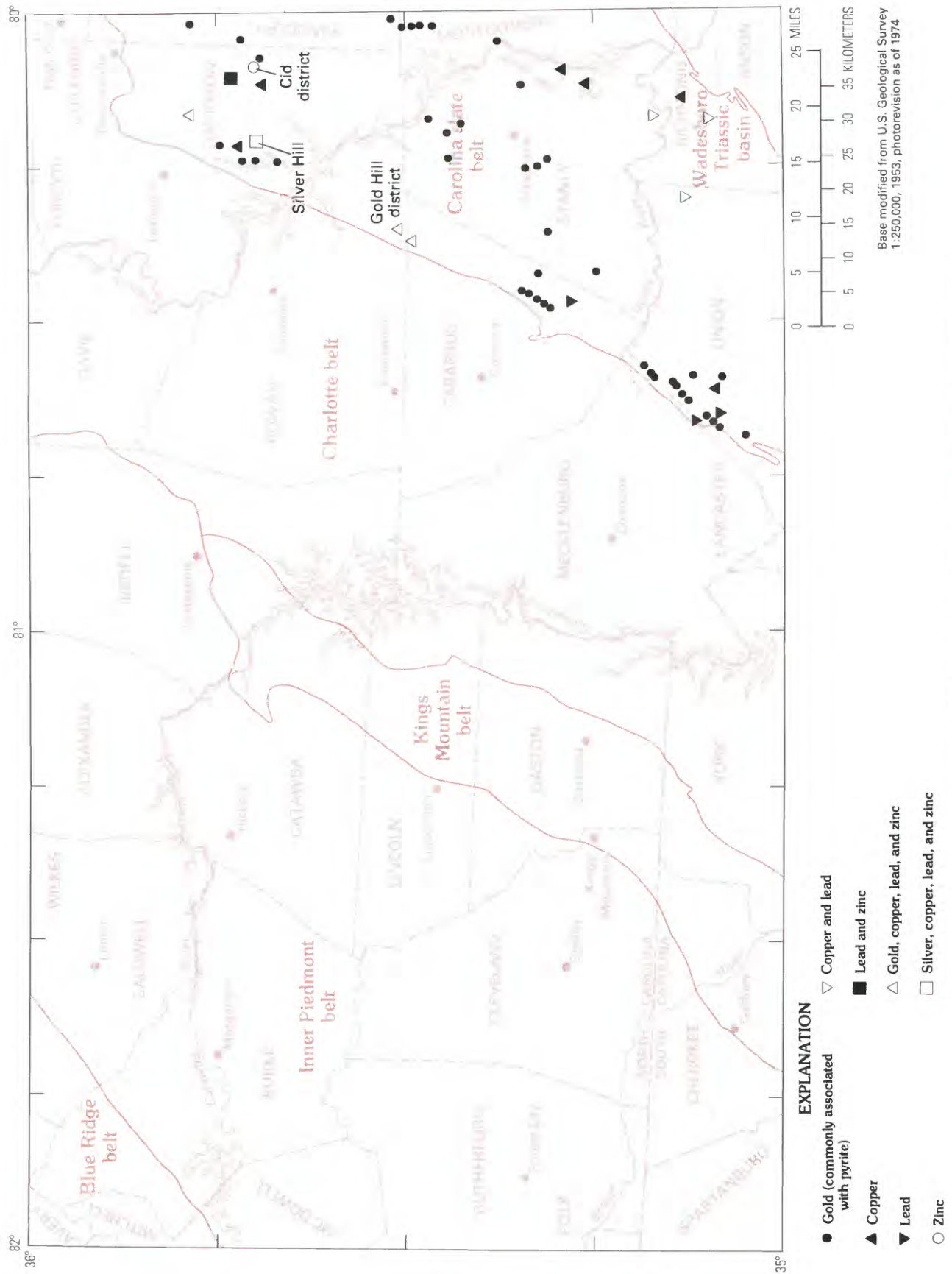


FIGURE 14. —Precious-metal and base-metal deposits in the Carolina slate belt, Charlotte quadrangle.

TABLE 2.— *Value, in dollars, of base-metal and precious-metal production from major deposits and districts of the Carolina slate belt in the Charlotte quadrangle*

[Reported values for year(s) of production prior to 1915]

	Metal produced	Value
Gold Hill district	Gold	3,300,000
	Copper	700,000
Cid district	Gold + copper	3,000,000
Silver Hill district	Silver + lead + zinc	1,000,000
Conrad Hill district	Gold + copper	170,000– 300,000
Emmons deposit	Gold	107,000

Types of associations with host rocks (mode of occurrence)

Massive-sulfide bodies are lenses and layers conformable with bedding and (or) schistosity of host rocks. Sulfide bodies may occur at contacts of volcanic and argillitic or phyllitic sedimentary rocks or entirely within a single type of rock. Sulfides may also be disseminated along (within) selected volcanic or sedimentary layers and in silicified parts of such rocks. Quartz occurs mainly in veins and pods conformable within rock or sulfide layers or at contacts between different lithologies or sulfide bodies and rock layers. Locally, veins cross schistosity, generally at low angles, and small veins may branch across schistosity at large angles. Small quartz veins may branch from or intersect one another in reticulated networks. Gold occurs as disseminated grains of the native metal in both volcanic-sedimentary rocks and in the associated quartz veins, and as blebs of the native metal within pyrite (that is, auriferous pyrite in both rocks and veins). Gold and copper or lead may be locally concentrated in gossan or saprolite that formed by the weathering of mineralized rock or veins.

Controlling structures or relation to nearby rock bodies

No controlling structures known. Commonly orebodies dip steeply, conformably with layered host rocks. Trend of mineralized zones and host rocks generally north to north-northeast. Deposits believed to be syngenetic with host rocks.

Mineralogy

Dominant ore minerals: Variable from one deposit to another; pyrite (for gold); chalcopyrite in most deposits (subordinate to abundant pyrite, which, however, has not been an ore mineral in its own right, but only for gold); sphalerite and galena in a few deposits, principally the Silver Hill and Silver Valley deposits.

Minor sulfide minerals: Arsenopyrite, pyrrhotite, covellite.

Gangue minerals: Quartz, carbonates, sericite, chlorite.

Geochemical and mineral indicators

Base-metal values in panned concentrates greater than 200 ppm. Concentrations of sphalerite, galena, limonite pellets, oxidized pyrite, and (or) gold in heavy-mineral concentrates.

Geophysical indicators

Generally none. INPUT² anomalies or other electromagnetic anomalies commonly are present over massive-sulfide deposits and may mark some deposits in the Carolina slate belt.

RESOURCE ASSESSMENT

Areas containing previously mined deposits constitute areas of identified resources of the commodities gold, base metals, silver, and sulfur (from pyrite). Areas adjacent to those containing identified resources and underlain by Carolina slate belt rocks similar to those containing the known deposits are considered to be zones of high resource potential. Other Carolina slate belt areas of felsic or andesitic volcanic rocks and argillite or phyllite that are not adjacent to mined deposits but that contain mineral occurrences, some of which have been prospected, also have a high resource potential (for mineral discovery). There are a number of such areas in the slate belt portion of the Charlotte quadrangle. The principal areas of high resource potential are (1) in the Gold Hill district, Rowan County, about midway along the west edge of the slate belt in the quadrangle, and (2) in the Silver Hill and Cid districts, 25 to 32 km northeast of the Gold Hill district (fig. 14; Gair and Griffiths, 1986). One area of high resource potential for lead and zinc near the northeast corner of the quadrangle is adjacent to rather than within the slate belt and is associated with an unnamed granitic pluton. Numerous areas a few miles or less in diameter in the Carolina slate belt have a moderate potential for resources of stratabound sulfides and gold as deduced from the presence of appropriate geochemical (trace-element) and heavy-mineral concentrations (Gair and D'Agostino, 1986; Gair and Griffiths, 1986). Other parts of the slate belt, which have no known mineral occurrences or unusual geochemical or heavy-mineral concentrations on strike from such concentrations in the same formations, have a low potential for the resources being considered here. The outline of such areas coincides with the boundaries of specific formations of the slate belt, excluding the already designated areas of high and moderate potential.

²INPUT is an acronym for a type of electromagnetic survey that measures "induced pulse, transient" fields and their decay rates.

Stream drainages containing visible particulate gold emanate from a number of areas of comparatively high ground in the Carolina slate belt that can be inferred to have yielded gold to the streams from lodes. A number of these areas, particularly along the west side of the slate belt and in the Cid district, correspond to areas of past lode mining for gold, but a number of such areas east, southeast, and south of Albemarle, N.C. (Gair and D'Agostino, 1986), have had no previous lode mining, so they are newly recognized areas having potential for lode gold resources. The largest area of potential gold resources in the slate belt is a zone about 10 km long and 5 km wide centering on Gold Hill (fig. 14; Gair and D'Agostino, 1986). This zone of favorable volcanic rock, in which a number of pan concentrate samples contained visible gold, is considered to have a high potential for low-grade gold resources.

Most potential stratabound sulfide deposits are probably small by national standards and contain less than 500,000 tons of sulfide each. This conclusion is supported by a comparison of the number of relatively sizable deposits (albeit of modest size) and the total number of sulfide and (or) gold deposits previously discovered in the slate belt. A tabulation of metal mines in the North Carolina part of the Carolina slate belt by Carpenter (1976) contains about 155 mines, all defunct. Probably at least two-thirds of the mines are in stratabound sulfide and (or) gold deposits. Most were small gold mines, and a number of them may have been situated on essentially the same deposit, so deposits may be somewhat fewer in number than the mines. Nitze and Hanna (1896) named a number of mines not listed by Carpenter, and many additional small mines exist in the slate belt for which there is no record or name (R.G. Schmidt, 1981, oral commun.). Only two or three of the known deposits in the North Carolina part of the slate belt are in the 200,000- to 500,000-ton (sulfide) range, and only three known

deposits (at the Haile, Brewer, and Ridgeway mines, South Carolina, south of the Charlotte quadrangle) in the entire slate belt are in the 1-million-ton class. The small number of modest-size deposits known relative to the total number of deposits and the absence of any deposits that are large by national standards indicate a strong probability that the ratio of large deposits (greater than 5 million tons sulfide) to future discoveries of this type of deposit will be small (1:100 or less).

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GOLD-QUARTZ AND GOLD-PYRITE-QUARTZ VEINS

By JACOB E. GAIR

GEOLOGIC SETTING AND SUMMARY OF MINING

Quartz veins were important sources of gold produced in the Charlotte 1°×2° quadrangle west of the Carolina slate belt from about 1825 to 1910 (fig. 15). Gold production from this source since about 1910 has been minor and took place mainly for a few years during the Depression and after the price of gold increased from \$20.67 to \$35.00/oz in the 1930's. Disseminated pyrite is common in veins, and some veins, especially in shear zones in the Kings Mountain belt, contain abundant pyrite. At the Oliver mine in that belt, veins of massive pyrite plus quartz occur in a major shear zone. The distinction is made here conceptually and genetically between quartz veins of the Carolina slate belt, discussed in the previous section, and those to the west, although veins and mineralization in both areas may be virtually identical in appearance. Most of the veins of the slate belt are considered here to be genetically related to the enclosing rocks and to have formed as part of the volcanogenic process. Veins to the west are diversely oriented, occurring principally in schists and granitic, biotitic, and hornblende gneisses of the Charlotte and Kings Mountain belts and the South Mountains area. Some are conformable to the schistosity of enclosing rocks, but many are crosscutting and are clearly epigenetic fissure fillings. Crosscutting veins commonly branch from conformable ones, so both probably formed together. Gold-quartz veins that are probably epigenetic are abundant in the Gold Hill-Silver Hill shear zone along the west side of the Carolina slate belt. Many gold-bearing quartz veins in the Kings Mountain belt, including those of the Smyrna district, S.C., are in the upper parts of subvolcanic intrusions and in altered zones of the surrounding metavolcanic rocks and quartz-mica schist (Butler, 1981). Deformation and metamorphism have partly redistributed and differentiated the ore minerals. Epigenetic gold-pyrite-quartz veins and gold-pyrite veins are particularly common in shear zones. The Kings Mountain mine on the Kings Creek shear zone and the Long Creek and Oliver mines on the Long Creek shear zone are examples (Horton, 1981, p. 12). The major ore at the Kings Mountain mine was in gold-pyrite-quartz veins

ranging from 0.6 to 6 m in thickness, but segments of brecciated marble mineralized by sulfides were sufficiently rich to be milled (Keith and Sterrett, 1931, p. 4). The value of gold produced from veins west of the slate belt cannot be determined accurately because production data from veins and placers in this area have not been separately identified in production records now available.

The greatest known concentration of gold-quartz veins is in about 1,550 km² of Mecklenburg County in the Charlotte belt, where gold was produced from about 100 mines, many located within 15 km of the city of Charlotte. Productive veins also are distributed widely in the Kings Mountain belt, mainly in Cleveland, Gaston, Lincoln, Catawba, and Davie Counties, N.C., and in the Smyrna district of Cherokee and York Counties, S.C.

Other gold-quartz veins of the quadrangle occur principally in the South Mountains area of Burke, McDowell, and Rutherford Counties; these veins are narrow, commonly less than 0.5 m in thickness, and were mined only by hydraulic treatment of strongly weathered rock and saprolite (see section of this report on saprolite deposits). The largest productive deposit of the gold-quartz vein type was at the Rudisil mine, located about 2 km southwest of Charlotte, N.C., in the Charlotte belt. Total gold production at this mine from about 1830 to 1903 has been estimated to be between 25,000 and 50,000 oz. Ore varied in grade from about 0.25 to 11 oz/ton but averaged between 0.3 and 0.5 oz/ton. The Kings Mountain mine had a similar production, mostly from gold-pyrite-quartz veins, which yielded an estimated 36,000 to 48,000 oz of gold from ore averaging about 0.4 oz/ton (Pardee and Park, 1948, p. 74). In the Charlotte area, the second most productive deposit (actually several closely grouped veins) was at the Capps Hill and McGinn mines, 7 to 8 km northwest of Charlotte. Production there was only about one-tenth that of the Rudisil mine (about 2,900 oz; no data on grade are available).

DESCRIPTIVE MODEL

Size of veins

Length: Mainly 10 to 100 m; maximum recorded about

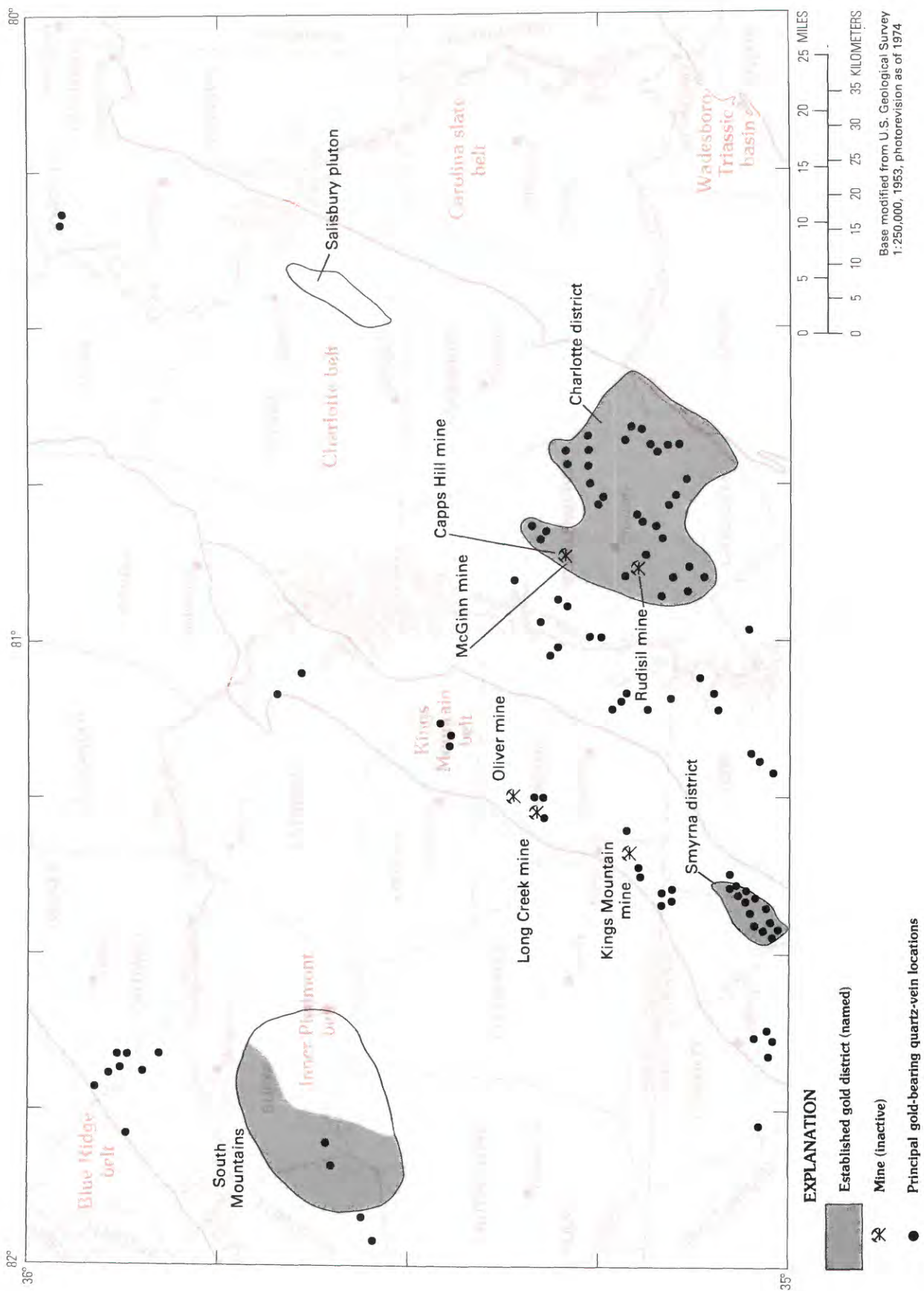


FIGURE 15.—Gold-quartz veins in the Charlotte quadrangle, west of the Carolina slate belt. Major areas of gold-quartz veins are shaded.

915 m; systems of veins as much as about 3 to 4 km long.

Width: Mainly 0.6 to 5 m (thinner veins common but not generally mined). Thickest about 6 to 7 m. Most veins in South Mountains area less than 0.3 m; only thicker veins in saprolite of that area, 0.6 to 1.2 m thick, were mined by hydraulic methods.

Depth: Maximum depth of mining about 115 m. Ultimate depth of mineralization unknown.

Grade: 0.05 to 11 oz/ton; average about 0.3 oz/ton, in the range of 0.2 to 0.4 oz/ton at different deposits.

Lithology of host rocks

Granitoid gneiss; biotite gneiss; hornblende gneiss; metatonalite; metavolcanic rocks; quartz-mica schist. Several deposits, including the Rudisil, have been described as quartz veins in a narrow belt of schist or slate confined within granite or granite gneiss and are considered to be either an alteration zone of the granitoid rock or roof pendants of country rock. Host rock of gold-pyrite-quartz veins of the Kings Mountain mine is a graphite-bearing chlorite-white-mica phyllonite containing minor lenses of marble.

Types of associations with host rocks (mode of occurrence)

Veins are both conformable lenses parallel to schistosity and gneissic foliation, anastomosing in places, and tabular lenticular bodies that pinch and swell and crosscut gneiss, schist, and pegmatite. Vein ladder structure and reticulated networks are present in places. Gold occurs as native metal disseminated in quartz and within grains of pyrite and chalcopyrite disseminated in the quartz veins.

Controlling structure or relation to nearby rock bodies

Veins controlled mainly by rock schistosity (foliation) and fractures, which probably include faults that cross schistosity. Some veins may lie along boundaries between different types of country rock. Schistosity trends mainly northeastward; common directions of crossing structures are northwestward and northward.

Mineralogy

Metallic minerals: Pyrite, chalcopyrite, gold.

Gangue minerals: Quartz, muscovite, carbonate (commonly siderite).

Geochemical and mineral indicators

Chemically analyzed gold in stream sediment or soil samples.

Native gold in pan concentrates or heavy-liquid mineral separates.

Geophysical indicators

Generally none.

RESOURCE ASSESSMENT

Individual quartz veins are too small to be shown on the map at a scale of 1:250,000, so areas of identified resources of lode (vein) gold are limited on the quadrangle map to small spots centered on and immediately surrounding the mined lode deposits (D'Agostino and Rowe, 1986). On the map of gold resource potential (Gair and D'Agostino, 1986), areas broadly favorable for gold resources are defined by combining such data on the locations of known once-viable deposits with other evidence for the presence of gold obtained during the present survey. Such evidence consists primarily of particulate gold actually seen in pan concentrates and gold detected in pan-concentrate samples by spectrographic analysis.

Identified gold resources from veins occur principally in the vicinity of Charlotte, N.C., in the central and southern part of the Kings Mountain belt, and in the South Mountains. Major areas of high resource potential are adjacent to some of the areas of identified resources. Gold in the stream-sediment samples collected during the CUSMAP program is directly applicable to the evaluation of potential gold placer resources rather than veins, but much of this gold probably also reflects potential resources in lode deposits within the respective drainage basins. The drainage basins, as outlined around sites where particulate gold was seen in pan concentrates (Gair and D'Agostino, 1986), do not generally represent complete stream drainage systems; instead they are a portion of such systems as much as 4 to 5 km long, conservatively drawn mainly or entirely along the actual stream in which the gold was found and not along the tributaries. Several areas of the quadrangle in which such gold-bearing drainage basins are closely grouped are probably also areas containing numerous lode sources of the particulate gold in the stream sediments; such areas therefore are considered to have high potential for lode gold resources even though there has been little or no production of lode gold from them. These areas are located (1) in the Charlotte belt over the south part of the Salisbury granite pluton and an adjoining unit of metavolcanic rock, (2) in the northern part of the Kings Mountain belt, (3) in the north-central part of the quadrangle adjacent to the boundary between Alexander and Iredell Counties, (4) in the northwest part of the quadrangle adjacent to the Brevard fault, and (5) in the southwestern part of the quadrangle (see section on placer deposits for locations of particulate gold in stream sediments). Despite high potential for the occurrence of lode gold in these areas, deposits probably are generally low in grade. Richer veins such as those previously mined may have grades of as much as 0.4 oz/ton.

Some of the closely grouped streams in which particulate gold has been found flow from common headwaters areas, which may contain the lode (vein) sources of the placer deposits (Gair and D'Agostino, 1986), and indeed, past production from lode mines has been recorded from several such headwaters areas near Charlotte, N.C., from the Smyrna district near the south end of the Kings Mountain belt in the quadrangle, and from the Brown Mountain area north of Morganton, N.C.

No areas of moderate potential for gold resources from veins are defined in the quadrangle because of a lack of appropriate data; areas of moderate potential, in a scheme corresponding to that for evaluating the resource potential of other metallic minerals, would be defined by known quartz or pyrite veins and the presence of chemically analyzed or particulate gold in the sampled material.

The aggregate volume of quartz-vein gold at minable deposits in the area may be large (that is, comparable to or greater than the amount already produced), but because the deposits are probably in numerous small and widely dispersed veins, the resource potential of such gold deposits must be low.

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PLACER DEPOSITS (GOLD, MONAZITE, CASSITERITE, ZIRCON, ILMENITE, RUTILE)

By JACOB E. GAIR, JOHN P. D'AGOSTINO, and JESSE W. WHITLOW

GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

Placer deposits are concentrations of heavy minerals in unconsolidated material; the minerals can be recovered by washing the material with water. Typically, the unconsolidated material is a mixture of alluvial gravel, sand, and clay in a stream channel. Such alluvial placer deposits within the Charlotte quadrangle have been important sources of gold and thorium (an impurity in the heavy mineral monazite) and minor sources of rare earths (also from monazite), tin (from cassiterite), and zirconium (from zircon). Such placers also are potential sources of the titanium minerals ilmenite and rutile.

Placer mining began with the first recovery of gold in the earliest years of the 19th century. In the quadrangle, the most important placer gold deposits have been in (1) Cabarrus and Stanly Counties in the Carolina slate belt, (2) Mecklenburg County in the Charlotte belt, (3) Gaston County in the Kings Mountain belt, (4) Catawba County in the Inner Piedmont belt, and (5) Burke, McDowell, and Rutherford Counties in the South Mountains area of the Inner Piedmont (fig. 16; D'Agostino and Rowe, 1986; Gair and D'Agostino, 1986). Monazite was recovered by placer mining from 1886 to 1910, principally in Burke, McDowell, and Rutherford Counties but also in Alexander, Catawba, Cleveland, Gaston, Iredell, and Lincoln Counties (Overstreet, 1967, p. 197–198, 205–206, 209, 226; D'Agostino and Rowe, 1986; Gair, 1986b). Common source rocks for monazite are bodies of granite (especially Toluca Granite), quartz monzonite, pegmatite, biotite gneiss, sillimanite schist, and various granitized schists (Overstreet, 1967, p. 196–206). The minor commodity minerals recovered from alluvial placers have been byproducts of the recovery of gold or monazite, the most notable being cassiterite in the Kings Mountain belt (Kesler, 1942; D'Agostino and Rowe, 1986, Gair, 1986c). Alluvial placer deposits from which gold has been commercially recovered range from about 3 to 180 m in width and average 20 m, 1 to 5 m in depth, and a few tens of meters to 9 km in length. Gold placers generally are less than 500 m long east of the Inner Piedmont, whereas the largest gold placers are in the South Mountains of the

Inner Piedmont. The tenor of gold in these deposits commonly is 0.07 to 0.09 g/m³ (0.002 to 0.025 oz/yd³). The range is from well below the least amount of gold visible in pan concentrates to near the upper limit of visible gold panned in low-grade placers (see table 3 for ranges of gold in placers of different grades). Flood plains in the areas of monazite placers are 3 to 750 m wide and may be as much as 4 to 5 km long. About half are more than 60 m wide and contain more than 750,000 m³ of sediment. The recovery of monazite and zircon from such sediments ranged from about 60 g/m³ to 29 kg/m³ for monazite and 60 g/m³ to 17.5 kg/m³ for zircon (Stuckey, 1965, p. 490).

Source rocks for gold placers are mainly gold-quartz veins. For monazite, the source rocks are intrusive granite and quartz monzonite surrounded by biotite gneiss and sillimanite-almandine schists or pegmatite surrounded by a variety of rocks.

DESCRIPTIVE MODEL

Size and tenor of placers

Length: Few tens of meters to about 9 km. Gold placers in the South Mountains are 200 m to 9 km long.

Width: 2 to 3 m to about 750 m; most are gold placers, less than 50 m and average about 20 m; about half of the monazite placers (flood-plain deposits) are 60 to 250 m.

Depth: 1 to 5 m.

Volume of placers: Few hundred to about 45 million m³ of material containing recoverable heavy-mineral concentrates.

Tenor: 0.07 to 0.9 g/m³ of gold; 60 g/m³ to 29 kg/m³ of monazite; 60 g/m³ to 18 kg/m³ of zircon. Monazite contains 4.5 to 7.5 percent ThO₂. Many placers contain more than 1 percent titanium in the form of ilmenite and (or) rutile.

Lithology of host rocks

Placers form over or downstream from many source rocks of the quadrangle (plutonic and metasedimentary gneisses and schists, metavolcanic schists, and pegmatites).

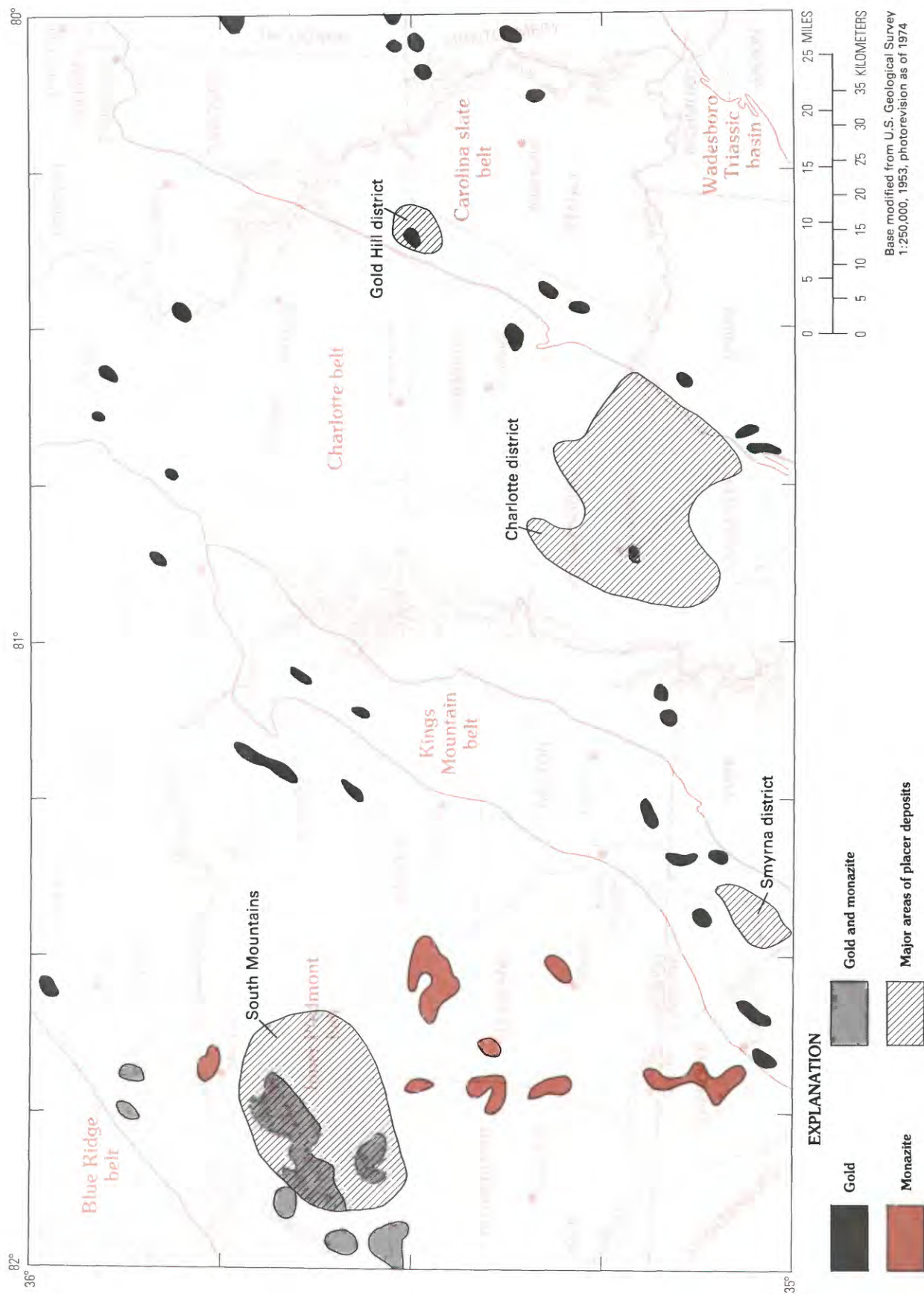


FIGURE 16. — Areas of former principal placer deposits in the Charlotte quadrangle.

TABLE 3.—*Range of visible gold (colors) in alluvial placers of the Charlotte quadrangle*

[Only placers of low and moderate grade were found during CUSMAP survey, by using 14-in (35-cm) gold pans holding approximately 9 kg of alluvial sediment each, dry weight. High-grade placers having the degree of richness shown here evidently existed in the past, judging from early reports, but none were found during the present survey]

Nature of visible gold	Weight of gold seen in pan (g)	Parts per million	Inferred grade of placer
Few particles of ~0.5 mm or less diameter.	~0.002–0.005	~0.2–0.5+	Low
Lag ribbon or "rooster tail" 1–2 cm long.	~0.01	~1.1	Moderate
Lag ribbon or "rooster tail" 2–3 cm long.	~0.1	~11	High

Mineralogy

Heavy minerals: Gold, monazite, cassiterite, zircon, garnet, rutile, ilmenite, xenotime.

Geochemical and mineral indicators

Particulate and chemically analyzed gold, monazite, zircon, cassiterite, and any of the other minerals listed above, appearing in heavy-mineral concentrates in above-average amounts. Chemically analyzed tin, beryllium.

Geophysical indicators

None.

RESOURCE ASSESSMENT

Placers that have been worked previously for gold or monazite (D'Agostino and Rowe, 1986) have little further potential for the minerals previously recovered but may have low to high potential for other placer minerals known to be present in greater amounts than background. Concentrations of gold, monazite, or other minerals in alluvium are tantamount to having a known mineral occurrence in bedrock; the placer setting, therefore, corresponds to a known mineral occurrence and favorable host rock. These are the diagnostic criteria used in this report for assigning a high resource potential. Thus, some of the previously worked placers are deposits of low to high potential for one or another of the heavy minerals not yet extracted: monazite (for thorium or cerium), zircon, columbite (for niobium), ilmenite, and rutile (see Duttweiler and others, 1985; Griffiths, Whitlow, and others, 1985a; Siems and others, 1985; and Gair, 1986a, for locations of high geochemical values indicating some of these substances). Perhaps the most interesting placers having resource potential are those discovered during the CUSMAP program that are gold- or cassiterite-bearing in places where these minerals were

not known previously (D'Agostino and Whitlow, 1985; Griffiths, Whitlow, and others, 1985b; Gair, 1986c; Gair and D'Agostino, 1986).

Many such occurrences of gold collected during the present survey (table 4) that are distinct from previously known placer operations are isolated with respect to other occurrences of gold in stream-sediment samples and represent local sources, probably small quartz veins. In some other parts of the area, however, a large proportion of adjacent sample sites contain gold, thereby outlining both the recognized districts and some potential districts (fig. 17). The tenor of gold in the sediments is generally low (<0.5 ppm or 0.0005 g/kg of stream sediment panned) (table 3).

The areas in which gold has been detected visibly are considered to range from high to low resource potential for minimum visible gold, which constitutes only about 0.2 ppm or less of a placer deposit. A few moderately rich placers in the area yielded about 0.01 g of gold per pan of sediment, but none yielded a lag ribbon or "rooster tail" as long as 2 to 3 cm in the panned concentrate, corresponding to high-grade material in a placer (table 3).

Nonmagnetic fractions derived from the original pan concentrates have been analyzed spectrographically for gold; many of these samples contain no visible gold. The distribution of such samples having chemically detectable but invisible (occult) gold is shown in figure 17. Typically, these nonmagnetic fractions weigh 0.2 to 13 g (probably averaging between 1 and 5 g) and represent about a 2,000- to 10,000-fold reduction in the weight of the original pan of sediment. If the maximum weight of gold, 0.005 g (table 3), recovered in a pan of sediment from a placer here classified as low grade was all concentrated in the nonmagnetic fraction of the original sample, and if this fraction weighed 5 g, the original proportion of gold in the pan would be upgraded from 0.5 ppm to about 1,000 ppm. A few actual spectrographic values of greater than 1,000 ppm were measured in the nonmagnetic fractions, but most of the fractions containing gold measurable spectrographically have 20 to 200 ppm gold; these values suggest that the tenor of the original unconcentrated sediment was about 0.01 to 0.1 ppm. This substantiates the conclusions that much of the gold identified spectrographically could not have been visible in the pan concentrate and that almost all placers from which such gold was derived are low grade.

As noted in the section on gold-quartz deposits, stream-sediment gold occurrences reflect a low potential for lode gold in the respective drainage basins (see outlined areas of stream drainage, Gair and D'Agostino, 1986) and extend beyond the outlined areas where such areas are less than the complete drainage basin. The relation between gold detected in stream sediments

TABLE 4.—*Localities in which appreciable quantities of gold were recovered by panning during CUSMAP*

Name of stream	Major stream or network	Quadrangle (7.5-minute or other as noted)	Location	Universal Transverse Mercator coordinates	Nature of gold occurrence
Palmetto ----- Branch	Brown Creek-PeeDee River	Ansonville, N.C.	1.5 km due south of Ansonville, Anson Co., N.C.	N. 3882600 E. 581380	Many small flakes of yellow gold.
Cabbage ----- Branch	Brown Creek-Pee Dee River	Ansonville, N.C.	2.0 km southwest of Ansonville, Anson Co., N.C.	N. 3882160 E. 580100	Many small flakes of yellow gold.
South Prong --- Buffalo Creek	Brown Creek-PeeDee River	Polkton, N.C.	14 km north-northeast of Polkton, Anson Co., N.C. (3 km northwest of Ansonville)	N. 3886300 E. 579160	Many small flakes and some coarse nodular grains of yellow-gray gold.
Little Meadow - Creek	Rocky River-PeeDee River	Mt. Pleasant, N.C. (15-minute quadrangle)	1 km due south of Reed Gold Mine (State Historical Park), Cabarrus Co., N.C.	N. 3903350 E. 548700	Coarse and hackly grains, yellow to white gold.
Dutch Buffalo -- Creek	Rocky River-PeeDee River	China Grove, N.C.	7 km due east of Kannapolis, Rowan Co., N.C.	N. 3932240 E. 543950	Many small flakes and hackly grains of yellow gold.
Bell Branch ----	South Yadkin River	Cool Springs, N.C.	15 km east of Statesville, Iredell Co., N.C.	N. 3964860 E. 524540	Wire and coarse grains of yellow gold.
Carroll Creek --	Johns River	Collettsville, N.C.	South side of Brown Mtn., 7 km southwest of Collettsville, Burke Co., N.C.	N. 3972250 E. 432950	Coarse grains of yellow gold.
Pearcey Creek -	Johns River	Chestnut Mtn., N.C.	5 km due south of peak of Brown Mtn., Burke Co., N.C.	N. 3970200 E. 431530	Coarse grains of yellow gold.
Mollys Branch--	Harper Creek-South Muddy Creek-Catawba River	Dysartsville, N.C.	3.0 km northeast of Dysartsville, McDowell Co., N.C.	N. 3942440 E. 423020	Hackly grains of yellow gold.
Molly Fork ----	First Broad River	Dysartsville, N.C.	9.0 km northeast of Dysartsville, McDowell Co., N.C.	N. 3932100 E. 424925	Hackly grains of yellow to white gold.
Jarretts Creek -	Broad River	Rutherfordton South, N.C.	11.0 km south of Rutherfordton, Rutherford, Co., N.C.	N. 3901260 E. 413735	Coarse grains of yellow gold.
Wolf Creek ----	Broad River	Kings Creek, S.C.	4.0 km due west of Smyrna, York Co., S.C.	N. 3877450 E. 457780	Small amounts of nodular yellow gold.
Guyonmoore --- Creek	Broad River	Kings Creek, S.C.	4.5 km southwest of Smyrna, York Co., S.C.	N. 3873560 E. 460180	Small flakes and nodular grains of yellow gold.

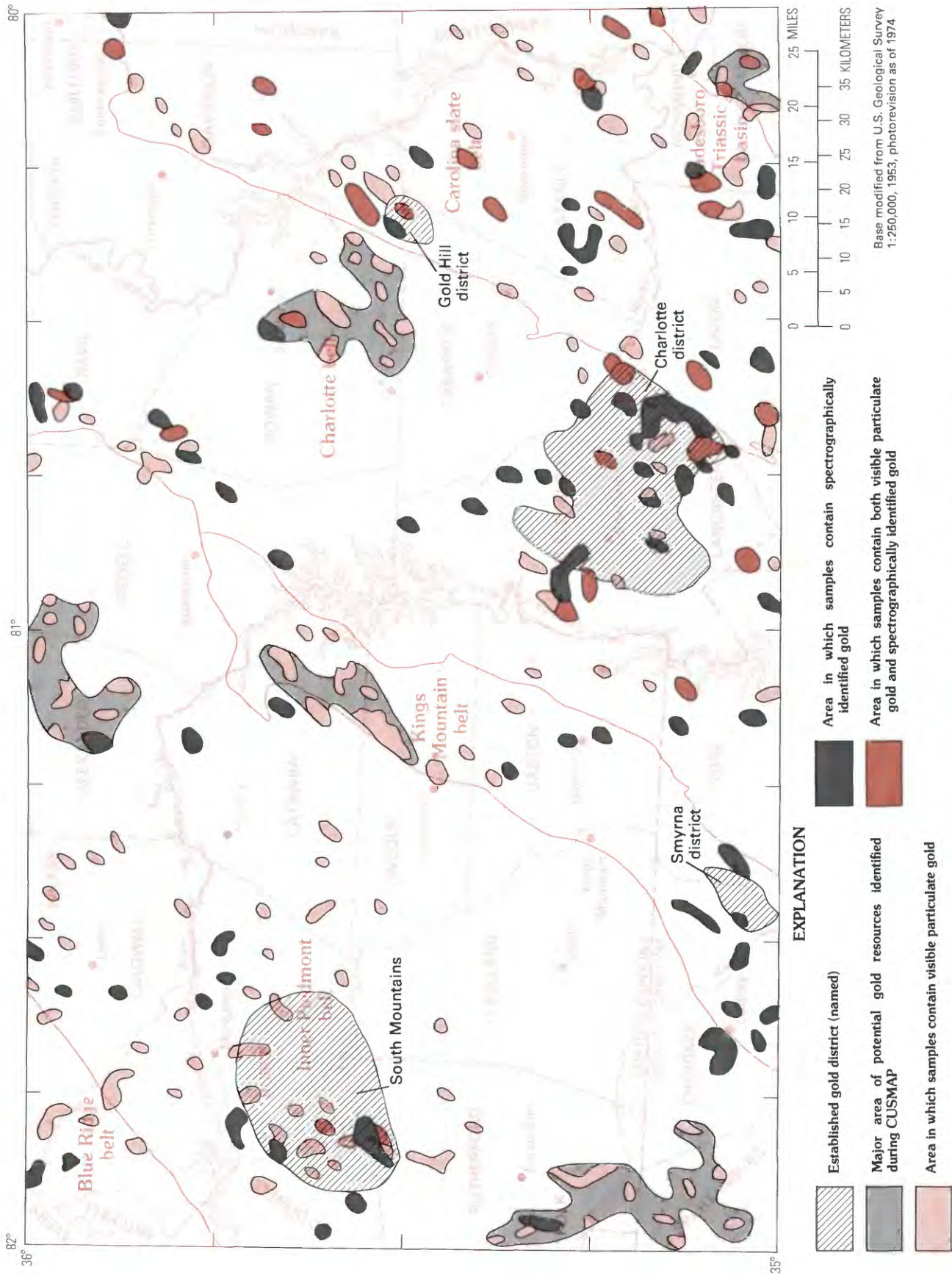


FIGURE 17.—Occurrences of particulate and spectrographically identified gold in the Charlotte quadrangle.

during the present survey and probable lode sources is well shown in the Smyrna district, South Carolina, in the south-central to southwest part of the Charlotte quadrangle (Gair and D'Agostino, 1986). Gold has been recovered from many lodes in this district and also is present in placers in many locations found during the present survey (fig. 17).

The principal gold-bearing areas are (1) the Smyrna district, S.C., (2) the South Mountains area, N.C., (3) the area in and around Charlotte, N.C., (4) the Gold Hill area, N.C., (5) midway along the Carolina slate belt in the quadrangle, and (6) the northern part of the Kings Mountain belt (fig. 17). Of these areas, the last has had only slight previous gold production, so the numerous gold-bearing samples found there during the present survey suggest a new potential gold district in that area. Other areas found during the present survey that have low resource potential for gold but where little or no previous mining has been done are (1) Triassic sedimentary rocks of the Wadesboro basin near the southeastern corner of the quadrangle and a zone in volcanic rock of the Carolina slate belt bordering the basin on the northwest (see also the section on gold in the Wadesboro basin by D'Agostino and Whitlow), (2) an area of metavolcanic rocks, mainly mafic, of the Charlotte belt intruded by Silurian to Devonian leucocratic granites of the Salisbury Plutonic Suite just east and northeast of Kannapolis, N.C., (3) two relatively small areas of metavolcanic rock, metagranite intrusive, and quartz veins in the Charlotte belt adjacent to the Eufola fault northeast of Statesville, N.C., near the common boundary between Iredell and Davie Counties, (4) several small areas northwest of Statesville in Iredell and Alexander Counties, underlain by interlayered sillimanite schist and biotite gneiss of the Inner Piedmont and intruded by a large pluton of Toluca Granite, and (5) an area in the Inner Piedmont in Rutherford County, N.C., and Cherokee County, S.C., in the southwestern part of the quadrangle, which is underlain by interlayered sillimanite schist and biotite gneiss cut by small bodies of coarse-grained granite of Sandy Mush (fig. 17; Goldsmith and others, 1988). Areas of occult, spectrographically detected gold, where there has been no previous gold mining, may be underlain by rocks containing widely disseminated, very small grains of gold not yet identified in the quadrangle.

Local concentrations of cassiterite were found in small placers along Hawkins Branch, 10 km southwest of Shelby, N.C., and in adjoining parallel south-flowing streams to the east and west and in some of their tributaries (fig. 18; D'Agostino and Whitlow, 1985; Griffiths, Whitlow, and others, 1985b; Gair, 1986c). The area drained by these cassiterite-bearing streams is approximately 900 km² and extends about 30 km west and south

from Shelby. Some cassiterite was found in pan concentrates taken from 36 streams in this area. Amounts of cassiterite recovered in panning along Hawkins Branch have been as much as 85 g from a single 14-in (35-cm) gold pan of alluvial sediment (approximately 9.5 g/kg of sediment or 0.95 percent), but the average estimated grade is 1.5 g cassiterite per kilogram of sediment. Hawkins Branch and the adjoining streams are small and shallow, so the cassiterite placers along them are correspondingly small. The area is judged to have a high potential for a small volume of cassiterite resources in placers. The total volume of alluvium in sandy gravel bars along the 3.5-km course of Hawkins Branch is estimated to be about 157 m³ or 307,250 kg,¹ which may contain 460 kg of cassiterite. The larger surrounding area, extending about 30 km west from Shelby and 30 km south to near Gaffney, S.C., has a potential for cassiterite resources, but not enough data are available to make an approximation of total resources. The possible geologic sources of the cassiterite in placers are discussed in the section "Cassiterite in tin-bearing pegmatites and griesens of the Inner Piedmont belt" and Griffiths, Whitlow, and others (1985b).

Overstreet (1967, p. 209-225) has presented detailed county-by-county data on monazite placer resources, citing estimated tons of resources and tenors for all major monazite-bearing stream systems of the Inner Piedmont belt in the Charlotte quadrangle. Estimates of monazite resources for parts or all of Catawba, Cleveland, Lincoln, Burke, McDowell, and Rutherford Counties were made principally by A.M. White or P.K. Theobald (Overstreet and others, 1959, p. 711) and total about 423,500 short tons at tenors of 0.4 to 3 lb of monazite per cubic yard of alluvium. A few streams have 3 to 4 lb/yd³, and one has 6 lb/yd³. According to Stuckey (1965, p. 490), the tenor of monazite placers ranges from 0.1 to 50 lb/yd³, with an average tenor of 0.8 lb/yd³. Tenors of zircon may range from 0.1 to 30 lb/yd³.

Many of the placers containing monazite and substantial amounts of zircon and ilmenite also may contain small amounts of rutile. Zircon commonly constitutes up to 20 percent of pan concentrates from stream sediments derived from suitable (mainly granitic) rocks² and may make up as much as 65 percent of a concentrate. Such placers containing large zircon fractions have a high potential for zircon resources. The titanium minerals also are widely present in other parts of the quadrangle in addition to the Inner Piedmont belt, and such areas have a low potential for titanium resources (Duttweiler and others, 1985).

¹Estimate assumes that 20 percent of the 3.5-km length of Hawkins Branch is in sandy gravel bars, 0.9 to 3.0 m wide and averaging 1.5 m in width and 0.075 to 0.3 m deep and averaging 0.15 m in depth.

²Visual estimates using fluorescent light.

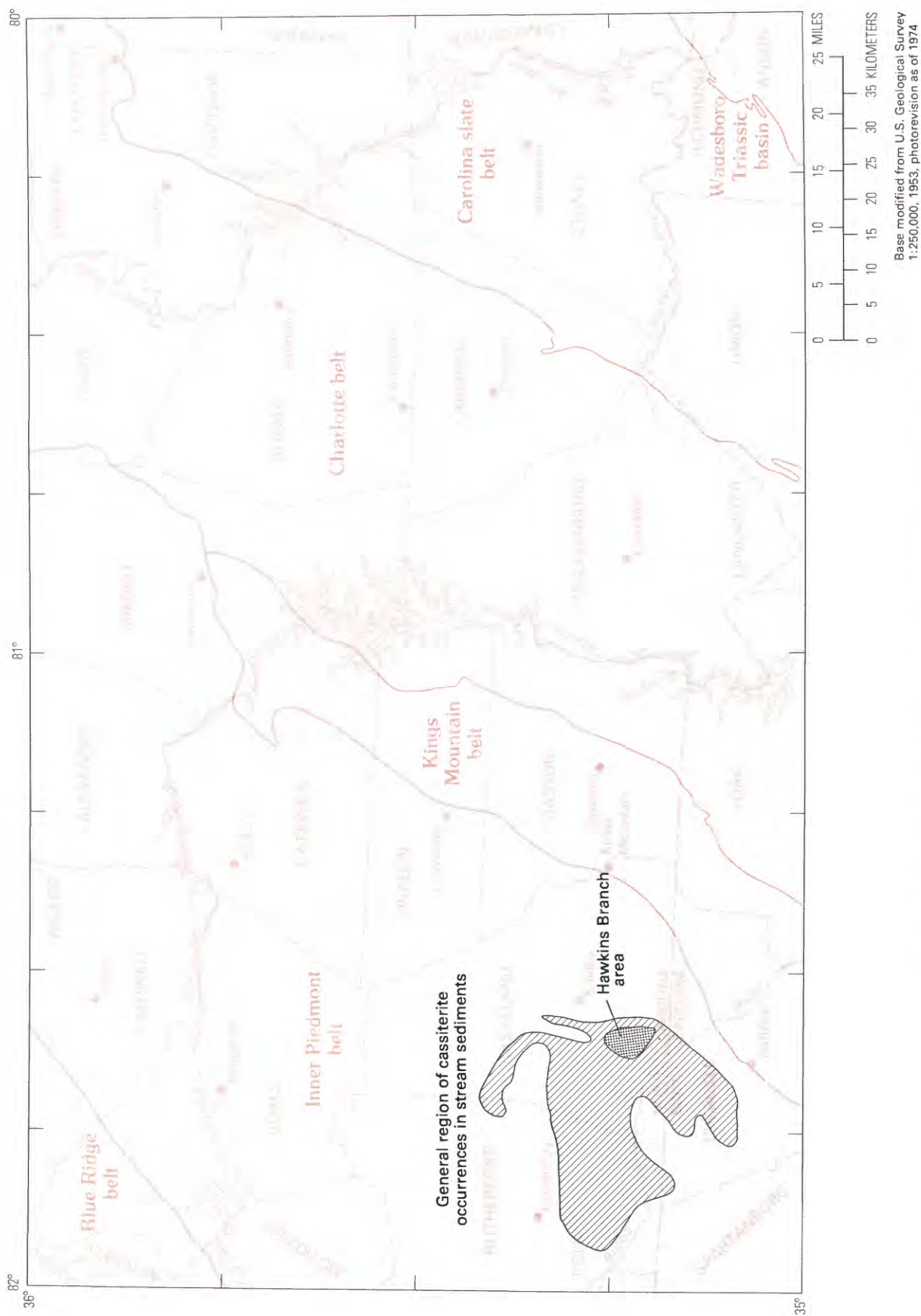


FIGURE 18. — Tin-rich area in the southwestern part of the Charlotte quadrangle.

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SAPROLITE DEPOSITS

By JACOB E. GAIR, JOHN P. D'AGOSTINO, PATRICIA J. LOFERSKI, and JESSE W. WHITLOW

GEOLOGIC SETTING AND MAJOR PRODUCTS

Saprolite is partially weathered rock that retains substantially the original rock volume, structure, and texture despite extensive oxidation of iron-bearing minerals and leaching of soluble components. Saprolite is part of the weathering profile developed over hard rock, and it is formed by the breakdown of primary minerals such as feldspar and mica to form clay minerals. Saprolite is distributed widely within the Southeastern United States and the Charlotte quadrangle. Saprolite zones range in thickness from about a meter to several tens of meters and locally to as much as 100 m, grading upward into the soil horizons and downward into less weathered rock. Deep saprolite is most likely to occur beneath remnants of relatively flat-surfaced upland areas. Several mineral commodities or potential commodities form by the processes that produce saprolite, namely the disaggregation and alteration of original minerals and (or) the residual enrichment of resistant minerals or alteration products as other components of the parent rock are leached.

A resource potential for saprolite (residual) clay exists in all the major geologic belts and is strongly dependent on the nature and depth of weathering; resource potential therefore cannot be assessed solely on the basis of the underlying type of rock. An investigation of the clay mineralogy of saprolite profiles, 6 to 18 m thick, developed over a variety of rocks in the Charlotte quadrangle shows that the clays are typically mixtures of kaolinite, halloysite, and fine-grained mica and lesser amounts of mixed-layer clays, vermiculite, and smectite (Loferski, 1981). Clays constitute from 3 to 75 percent of the saprolite, the remainder being sand, silt, and small rock fragments. Kaolinite and halloysite constitute 75 percent or more of the clays in most saprolites, but the ratio of kaolinite to halloysite varies widely, and both minerals are not necessarily present in any given deposit. Saprolite profiles studied by Loferski show overlapping ranges of clay content above various types of rock; clay ranges from 10 to 25 percent of saprolite above mica schist, from 40 to 70 percent above granite, from 5 to 20 percent above sericite schist, and from 10 to 45 percent above pegmatite.

Most saprolite clay is used as construction material; some is used for ceramics and other purposes. The clay present in saprolite is a residual product of weathering; other clay used for bricks occurs in alluvial deposits and in argillaceous rocks (after crushing and mixing with other clays). Saprolite clay for brick manufacture generally occurs mixed with other materials, especially quartz and feldspar sand and small rock fragments, and is found in all major geologic belts of the quadrangle (Gair and D'Agostino, 1986a). Bricks of assorted colors are produced from differently colored saprolites. Common red brick is derived from reddish saprolite, but other brick is made in deeper shades of red or dark gray, dark purple, or black by mixing in varying amounts of dark manganese clay. On the other hand, white to buff-color brick is made from light-colored to white saprolitized sericite schist.

The main area of mining has been over Cherryville Granite at the southeast edge of the Inner Piedmont belt near Grover, N.C. (fig. 19). High-quality kaolin clay suitable for ceramics is much less common and occurs mainly in the northwestern part of the quadrangle. This kaolin is derived from the weathering of alaskitic granite and pegmatite of the Spruce Pine district, which is centered a few miles west of the northwest corner of the Charlotte quadrangle. Scrap mica, disaggregated feldspar, and quartz also are recovered from saprolite. Scrap mica is a common byproduct of clay mining; in some places it is a principal product derived from granitic rocks, and clay may be the byproduct. Scrap mica commonly is recovered by hydraulic mining of saprolite over large areas—as much as 1 km long and 0.5 km wide in Avery County (fig. 19). Feldspar and quartz are recovered mainly if not entirely from near the southeast edge of the Cherryville Granite (see also the section "Feldspar and mica pegmatites").

Gold is both an established product of saprolite, having been recovered from weathered quartz veins within some gneisses and schists of the Inner Piedmont belt, and a potential product in a newly recognized type of occurrence. Gold has been recovered hydraulically, principally in the South Mountains area (fig. 19) by removing saprolite to depths of 10 to 15 m over areas of up to a few thousand square meters each. A potential new source of

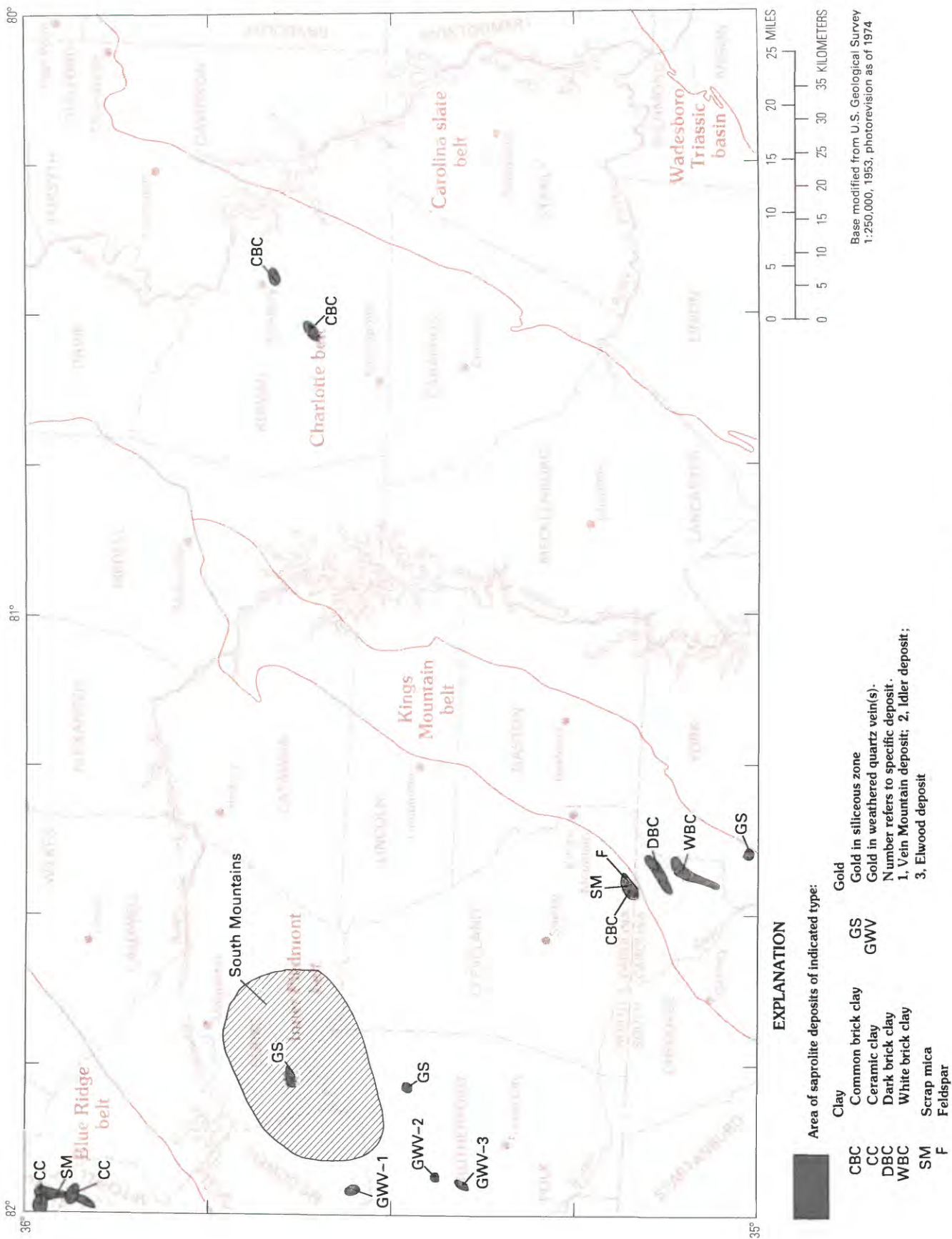


FIGURE 19. — Principal areas of saprolite deposits in the Charlotte quadrangle.

gold is siliceous zones in saprolite, subparallel to the land surface. Gold may have been dissolved in minute quantities from schist during weathering and reprecipitated in residual siliceous zones or quartz veins or, alternatively, concentrated by the residual enrichment of gold-quartz veins during weathering.

DESCRIPTIVE MODEL (RESIDUAL CLAY, SCRAP MICA, FELDSPAR, AND QUARTZ)

Size and grade

Diameter: Indefinite; general clayey saprolite zone may be many kilometers across, but deposits having quality suitable for exploitation are much smaller, up to about 1 km across.

Thickness: About 1 to 100 m; most are less than 60 m.

Volume (tonnage): Common brick clay—Enormous (about 200 million tons of production through 1978; total volume in area probably billions of tons).

Ceramic clay—Small to moderate amount (about 600,000 tons mined through 1978, but much of this probably was from two counties in the northwest corner of the quadrangle that lie mainly outside the quadrangle). Reserves in northwest corner of quadrangle of 2 to 4 million tons, but not all is of proven quality, and high-quality clay probably is less.

Scrap mica—Large (about 14 million tons produced through 1978). Total amount remaining in area probably many times the amount already produced.

Feldspar and quartz—Generally recovered as byproducts from saprolite of granitic rocks initially rich in these minerals.

Grade: (Clay only) 3 to 75 percent of saprolite is clay; about 75 percent of the clay is kaolinite and halloysite.

Lithology of host rocks

Most rocks in the quadrangle are suitable for common brick clay, given sufficient weathering. The most suitable rocks for common brick clay and scrap mica, feldspar, and quartz are oligoclase-rich granites and gneisses and schists rich in muscovite in the Blue Ridge, Inner Piedmont, and Charlotte belts; argillaceous or phyllitic rocks of the Charlotte belt and the Carolina slate belt are suitable for common brick clay but not for other saprolite products.

Types of associations with host rocks (mode of occurrence)

Form blanket of varying thickness; proportions of clay dependent partly on relative abundance of feldspar and (or) mica.

Controlling structure or relation to nearby rock bodies

None obvious. Possibly loci of shear or fracture zones cutting source rock are more vulnerable to effects of weathering than other parts of source rocks.

Mineralogy

Kaolin, halloysite, mixed-layer clays, muscovite-sericite, vermiculite, smectite, feldspar, quartz.

Geochemical and mineral indicators

Geochemical: None.

Mineralogical: High proportion of clay minerals.

Geophysical indicators

None.

DESCRIPTIVE MODEL (SAPROLITE GOLD)

Size and grade

Length: Veins—Individual veins, a few tens of meters; zones of thin veins may extend for many kilometers.

Siliceous zones—Unknown.

Width (thickness): Veins—Generally less than 1 m; clusters of veins common; as many as 33 parallel veins in a 0.5-km-wide belt at Vein Mountain and 13 parallel veins in a 0.5-km-wide zone at the Idler mine (see fig. 19 for locations of mines).

Siliceous zones—5 to 40 cm; known zones overlain by 10 to 50 m of saprolite.

Depth: Veins—Individual veins seen at surface probably do not extend more than a few tens of meters deep (exploration reported to 38 m). Depth of zones containing clusters of veins unknown.

Siliceous zones—Flat-lying to gently dipping zones only known within 50 m of surface (in roadcuts); possible extensions downdip not known.

Volume: Unknown.

Grade: Veins—About 0.5 oz/ton at Idler deposit, 0.25 oz/ton at Elwood deposit, and 0.12 to 3.5 oz/ton at Vein Mountain.

Siliceous zones—Unknown, but relatively low.

Lithology of host rocks

Gneisses and schists.

Types of associations with host rocks

Veins: Generally are crosscutting. At the Idler mine, country rock gneiss strikes N. 60° W. and dips 25° to 30° NE. while the veins strike N. 65° E.; at Vein Mountain, the regional strike is northeast, but the veins strike N. 80° E.

Siliceous zones: Flat-lying to gently dipping, subparallel to land surface above and transecting bedrock structures.

Controlling structure or relation to nearby rock bodies

Veins: Probably fracture zones transecting bedrock structures.

Siliceous zones: Land surface (water table?) may be controlling.

Mineralogy

Veins: Gold, quartz, pyrite, chalcopyrite.

Siliceous zones: Gold, quartz.

Geochemical and mineral indicators

Veins: Gold.

Siliceous zones: Gold.

Geophysical indicators

None known.

RESOURCE ASSESSMENT

RESIDUAL CLAY FOR BRICK

Several varieties of clay used for brick are represented on the map of construction-material occurrences (D'Agostino and Rowe, 1986) and on the map of clay resource potential (Gair and D'Agostino, 1986a). The source rocks for residual clay are principally (1) Cherryville Granite and related pegmatites along the southeastern side of the Inner Piedmont belt, which yield a light-colored clay with intermixed pieces of clay and feldspar, (2) metavolcanic rock, probably laced with granitic stringers, in the Charlotte belt near China Grove, N.C., (3) granite and phyllite just northeast of Salisbury, N.C., in the Charlotte belt, which yield light-pinkish clays, (4) spessartine-almandine garnet schist of the Kings Mountain belt, which yields a dark mixture of clay and manganese-iron oxides, and (5) quartz-sericite schist at the Kings Creek barite mine, S.C., which yields a light-colored to white clay-mica-quartz mixture (fig. 19; Gair and D'Agostino, 1986a).

The clay derived from granite and associated pegmatite is a major byproduct of mica and feldspar mining. The principal production has been from the Grover, N.C., mine of the Kings Mountain Mica Company (SM on fig. 19). The principal features of the rock from which the manganiferous clays are derived are discussed in the section by Horton dealing with manganese oxides derived from weathering of spessartine-almandine garnet in schist of the Kings Mountain belt. Principal features of the source rocks from which the light-colored clay-mica mixtures of the Kings Creek barite district are derived are presented in the section "Barite in quartz-sericite schist and schistose pyroclastic rock of the Battleground Formation, Kings Mountain belt."

Manganiferous slate in the northern part of the Kings Mountain belt (Nitze, 1893) produces a black saprolite that has never been used but that may be suitable for dark brick and tile. There is probably a large volume of such material, because the belt of manganiferous slate may extend for 25 km.

CERAMIC CLAY

High-quality kaolin clay suitable for ceramics, refractories, and face brick has a very restricted distribution in the Charlotte quadrangle; all is residual clay, and most is present near the northwest corner of the quadrangle (fig.

19) at the east edge of the Spruce Pine district and is formed by the weathering and saprolitization of feldspar (mainly oligoclase and microcline) in the alaskitic granite and pegmatite of this area. Two known deposits that are especially rich in kaolinite and (or) halloysite are the Brushy Creek and Gusher Knob deposits, just inside and straddling the west boundary of the quadrangle (Parker, 1946, pl. 2; Hunter and Hash, 1949; Bryant and Reed, 1966). Maximum thicknesses of clay reported are 18 to 27 m (Parker, 1946, p. 29, 34). Bryant and Reed (1966, p. 10) reported that 12 samples of the Gusher Knob deposit (from just outside the Charlotte quadrangle) contain an average of 47 percent hydrated halloysite, 12 percent kaolin, 24 percent quartz, 16 percent mica, and 0.5 percent feldspar. Probably the insignificant content of biotite and other femic minerals in the granitic rock and pegmatite of the Spruce Pine area, which could cause iron staining, and the deep weathering of remnant parts of the dissected upland near Spruce Pine account for the high quality of the clay. Parker (1946) estimated reserves in the Brushy Creek and Gusher Knob deposits to be 2 to 4.25 million tons of clay.

SCRAP MICA

Scrap mica is an important product of saprolitization of muscovite granites, both along part of the southeast edge of the Inner Piedmont belt (Cherryville Granite) and in the Blue Ridge belt (Lesure, 1968) near the northwestern corner of the quadrangle (Spruce Pine Alaskite). The occurrences in the northwestern corner of the quadrangle are derived from the same rocks as high-quality ceramic clay, and mica is a byproduct where clay is mined and a principal product where clay is not mined. Saprolite is stripped from areas as much as 1 km long and 0.5 km wide in Avery County and washed to recover scrap mica.

GOLD FROM WEATHERED GOLD-QUARTZ VEINS

In the South Mountains area, gold-quartz veins in saprolite, which are too thin to be mined individually, have been mined by hydraulic methods. These veins strike N. 60°-70° E., dip 70°-80° N., and are concentrated in five zones (Nitze and Wilkens, 1895, p. 67). Most veins are 0.5 to 1.5 cm thick; a few reach thicknesses of about 1 m. Veins may also contain a small amount of pyrite and base-metal sulfides. Such veins have been mined principally at the Vein Mountain deposit (also called Nichols mine) in McDowell County and at the Idler (also called Alta or Monarch) and Elwood deposits in Rutherford County (fig. 19; Nitze and Wilkens, 1897, p. 69; Pardee and Park, 1948, p. 77). Grades have been reported as high as 3.5 oz/ton at Vein Mountain, about 0.5 oz/ton at the Idler deposit, and 0.25 oz/ton at the Elwood deposit.

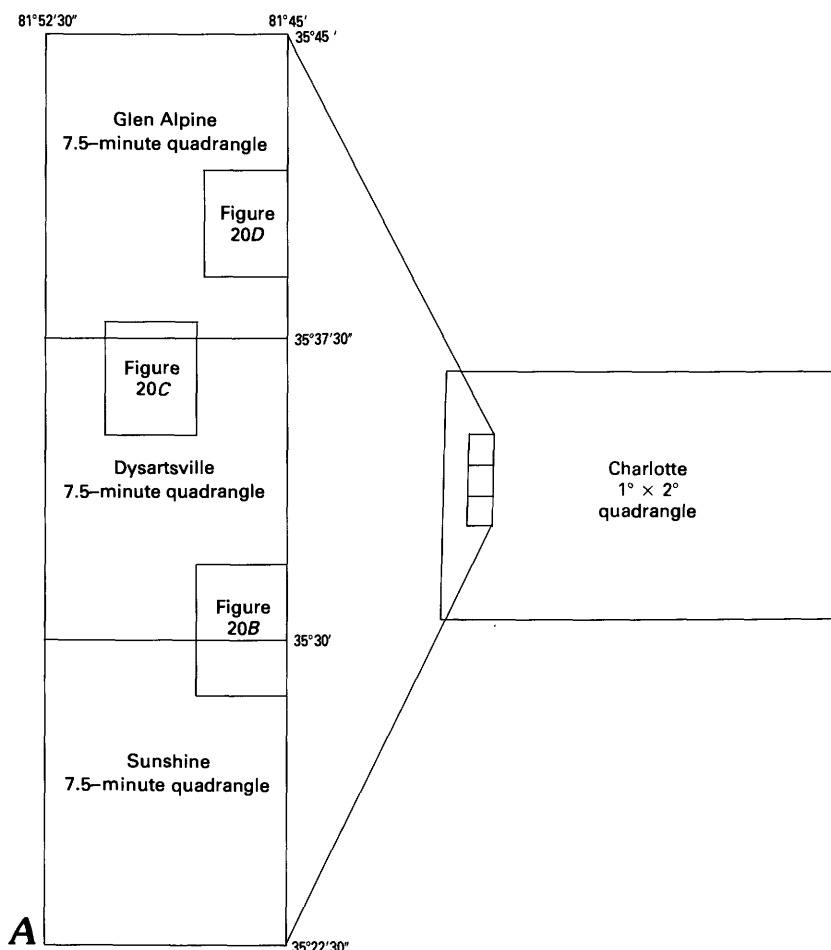


FIGURE 20.—Gold occurrences in siliceous zones in saprolite, South Mountains area, Dysartsville, Sunshine, and Glen Alpine, N.C., 7.5-minute quadrangles within the Charlotte quadrangle. A, Index map.

There is probably a high potential for additional resources of similar grades, but the total amount of gold available from this source is problematic and may not warrant development.

GOLD IN SILICEOUS ZONES IN SAPROLITE

During the CUSMAP study of the Charlotte quadrangle, a new potential source of low-grade gold was found in the South Mountains area (fig. 20; Gair and D'Agostino, 1986b) by two of the authors of this section, D'Agostino and Whitlow. This source is siliceous zones in saprolite, which can yield small bonanza pockets of coarse native gold. Gold-bearing siliceous zones are 5 to 40 cm thick and occur as horizontal to gently dipping layers. The thickness of saprolite overlying these zones commonly is 10 to 50 m. The siliceous zones occur in areas of gentle slopes and conform approximately to the land surface. The underlying bedrock is quartz-muscovite

schist of Late Proterozoic to Cambrian age containing disseminated finely crystalline auriferous pyrite. Siliceous zones have been seen to extend laterally for a few meters but are of unknown areal extent. These zones consist of white to gray, compact to vuggy quartz. Gold occurs within this quartz in flakes that are commonly 0.6 to 6 mm in diameter, may be as large as 2.5 cm, and may weigh 1 oz. D'Agostino found such occurrences of coarse gold in siliceous rock in saprolite in the following places: (1) in a ditch on the north side of State Route 1723 (Golden Valley Road), 1.7 km south of State Route 226 and 0.8 km due east of Cove Mountain peak, Rutherford County (southeast part of Dysartsville, N.C., 7.5-minute quadrangle, fig. 20B), (2) in a roadcut, east side of State Route 1723 (Golden Valley Road), 0.4 km north of State Route 1006 (Sunshine Road), and 5.0 km northeast of the town of Sunshine, Rutherford County (Sunshine, N.C., 7.5-minute quadrangle, fig. 20B), (3) in a deep roadcut,

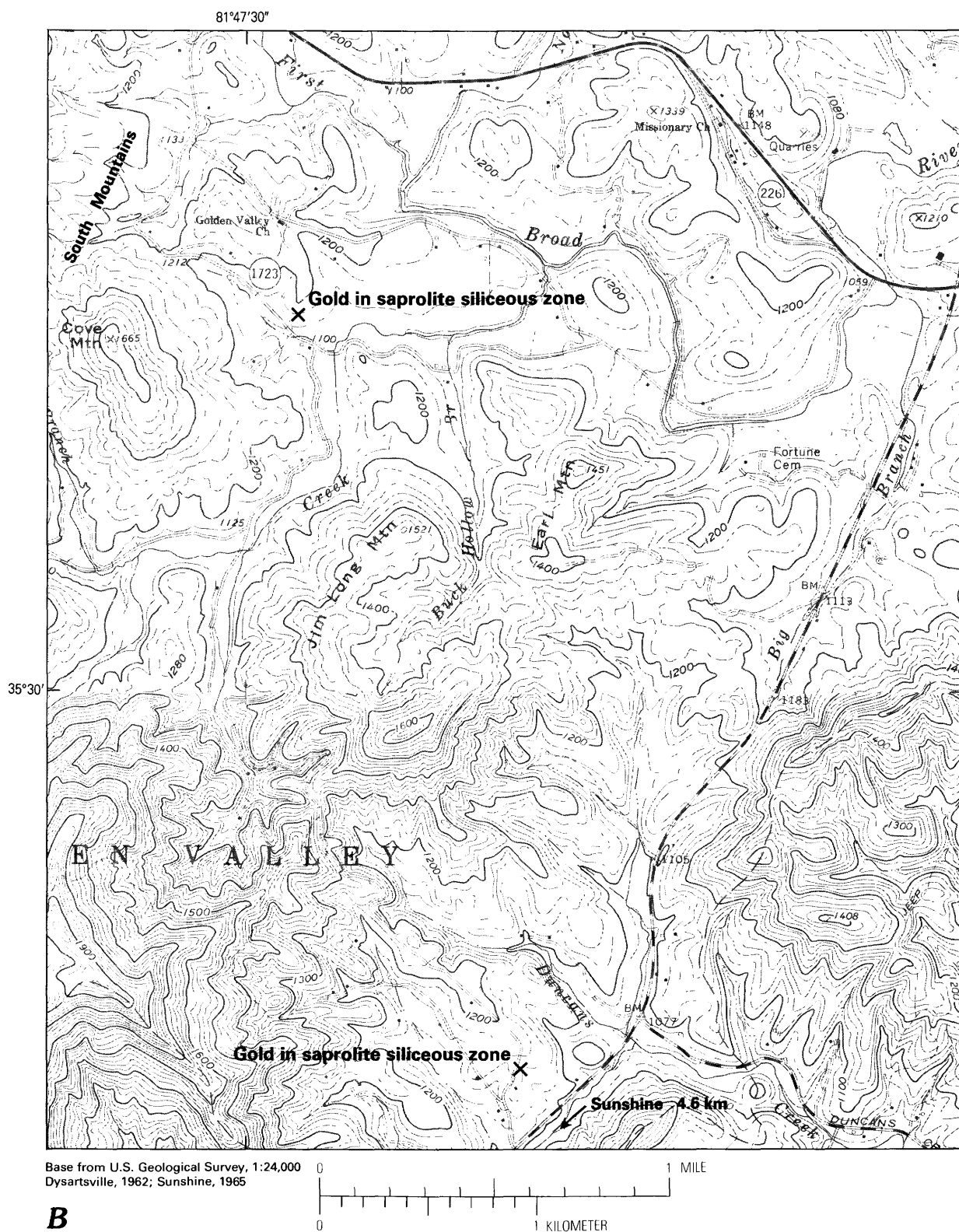


FIGURE 20.—Continued. B, Area southeast of Dysartsville and northeast of Sunshine.

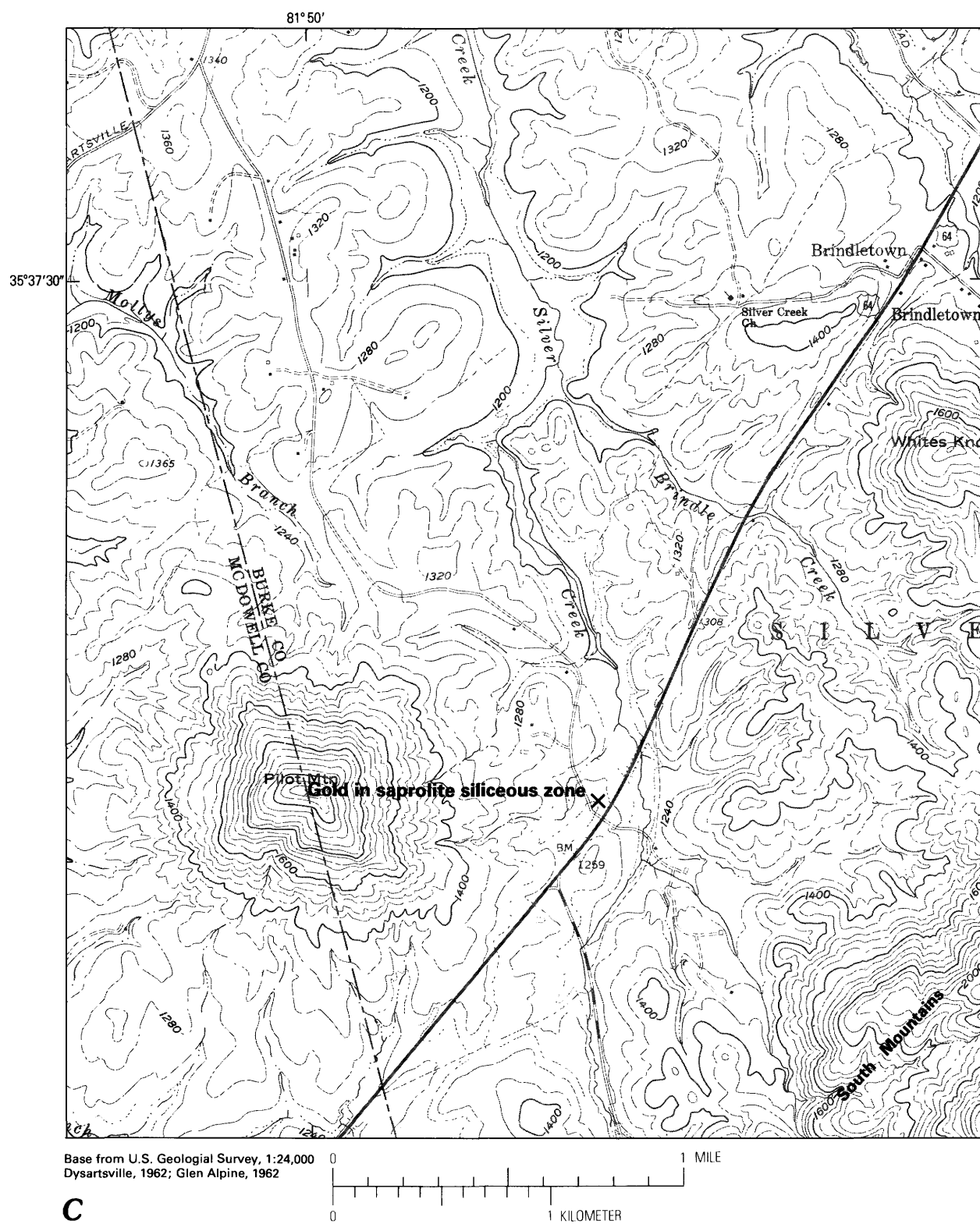


FIGURE 20.—Continued. C, Area east of Dysartville and southwest of Brindletown.

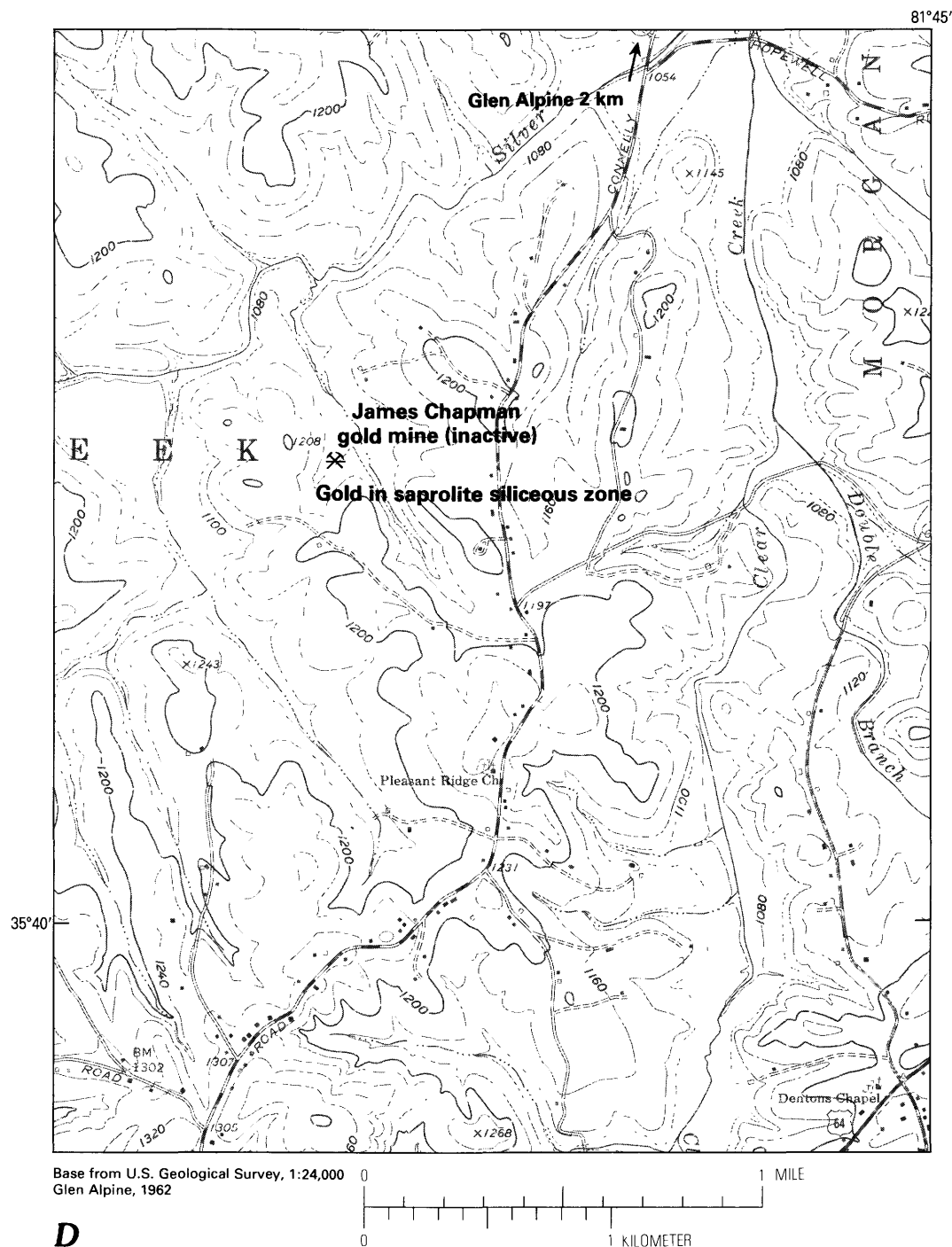


FIGURE 20.—Continued. D, Area of James Chapman gold mine, south of Glen Alpine.

northwest side of U.S. Route 64, 1.4 km due east of Pilot Mountain, 0.3 km south of Silver Creek, and 1.6 km north of the line between Burke and McDowell Counties in Burke County (Dysartsville, N.C., 7.5-minute quadrangle, fig. 20C), and (4) in the roof of an adit at the James Chapman gold mine, 5.0 km due south of Glen Alpine and 1.4 km north-northwest of Pleasant Ridge Church on

Connelly Road, Burke County (Glen Alpine, N.C., 7.5-minute quadrangle, fig. 20D).

The simplest explanation for these occurrences is that they are weathered gold-quartz veins that happen to conform approximately to topographic surfaces. However, the near parallelism of siliceous zones and topography and the unusually coarse size of gold flakes sug-

gest that the gold and perhaps also the quartz have been concentrated from the auriferous pyritic quartz-sericite schist by supergene processes during weathering. The movement and deposition of gold under supergene conditions has been described by Evans (1981) and Boyle (1979); this process also may explain the presence of coarse gold nuggets in stream sediments of the Southeastern United States, with no known occurrences of such coarse gold in lodes of the area (F.G. Lesure, 1981, oral commun.). Mertie (1959) described the formation of clear quartz crystals of supergene origin in saprolite but made a distinction between these and compact veins of white quartz, which he considered to be entirely hypogene. Few other accounts of the occurrence of compact layers or tabular bodies of quartz of supergene origin formed at or near the surface during weathering are known. Zones of silcrete (secondary silica) have been related to the ground-water table in saprolite in Australia (Dregne, 1976; Nickel and Thornber, 1977; Smith, 1977). Layers of silicified Precambrian dolomite in upper Michigan have been attributed to weathering and possibly diagenetic effects during late Precambrian time (James and others, 1968, p. 18–19). The most reasonable explanation for the coarse gold flakes may be that they are supergene, deposited during weathering. There are no data available on the possible extent or number of gold-bearing siliceous zones. Prospecting probably will require extensive drilling by churn drill holes as much as 50 m into saprolite to define the extent of siliceous zones, starting from a few exposures in roadcuts. We estimate that this type of deposit consists of small volumes of material having a moderate potential for low-grade gold resources ranging from 0.55 g/m ton (0.016 oz/short ton) to 4.33 g/m ton (0.14 oz/short ton).¹

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¹Grades calculated from amounts of gold recovered in individual pans of saprolite material from different locations, by using 9 kg as the weight of one pan of material. The large-scale recovery of gold from a saprolite deposit probably will yield some flakes of gold considerably coarser than commonly recovered in the individual pans of material.

COLLUVIAL DEPOSITS OF GOLD AND OTHER MINERALS

By JOHN P. D'AGOSTINO, SALLIE I. WHITLOW, and JACOB E. GAIR

DEFINITION AND DISTRIBUTION

Colluvial deposits of the Charlotte quadrangle are known mainly in the rugged terrain of the western part of the area (fig. 21). The term as used here refers to disseminated low-grade concentrations of heavy minerals in mixtures of disaggregated rock, saprolite, and soil, exclusive of the alluvium of stream bottoms and flood plains. This material typically has been transported downslope by soil creep and sheetwash; this transportation has caused some redistribution of heavier and lighter minerals and coarser material. It is also referred to as "eluvial" deposits. This type of colluvium in the South Mountains typically collects above saprolite on flat or gently inclined surfaces near the base of steeper slopes. In the South Mountains area, colluvial deposits commonly are found also in terracelike blankets mantling flatter parts of ridge shoulders. Heavy minerals (espe-

pecially gold, but also monazite and zircon) tend to be more concentrated in gravelly zones in the lower parts of colluvial bodies and so may be effectively hidden by younger colluvium and soil unless exposed in roadcuts or found by drilling. This type of deposit is newly recognized in the area, and not enough is known about it to construct a descriptive (occurrence) model.

Gold is the mineral of principal interest in the colluvial type of deposit (Gair and D'Agostino, 1986), although a large fraction of some pan concentrates may consist of zircon, and some concentrates are 2 to 3 percent monazite. The minerals columbite and thorite are rarely present in these deposits. Gold has been recovered by panning material from gravel-rich zones as much as 3 m thick in colluvium of the South Mountains. The known occurrences have been exposed in new roadcuts on U.S. Route 64 at Brindletown, Burke County (fig. 21B),

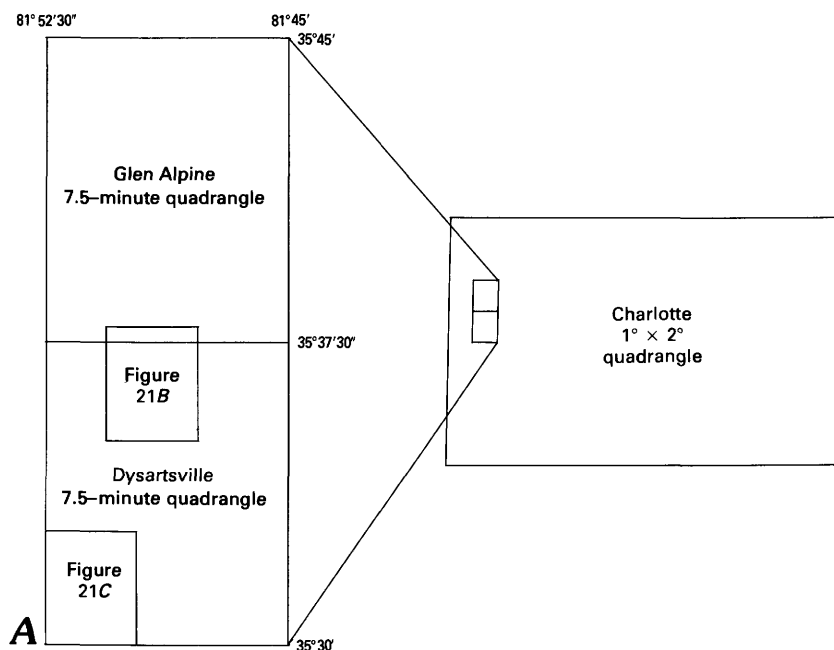


FIGURE 21.—Occurrences of gold in colluvium in the South Mountains area in the Dysartsville and Glen Alpine, N.C., 7.5-minute quadrangles within the Charlotte quadrangle. A, Index map.

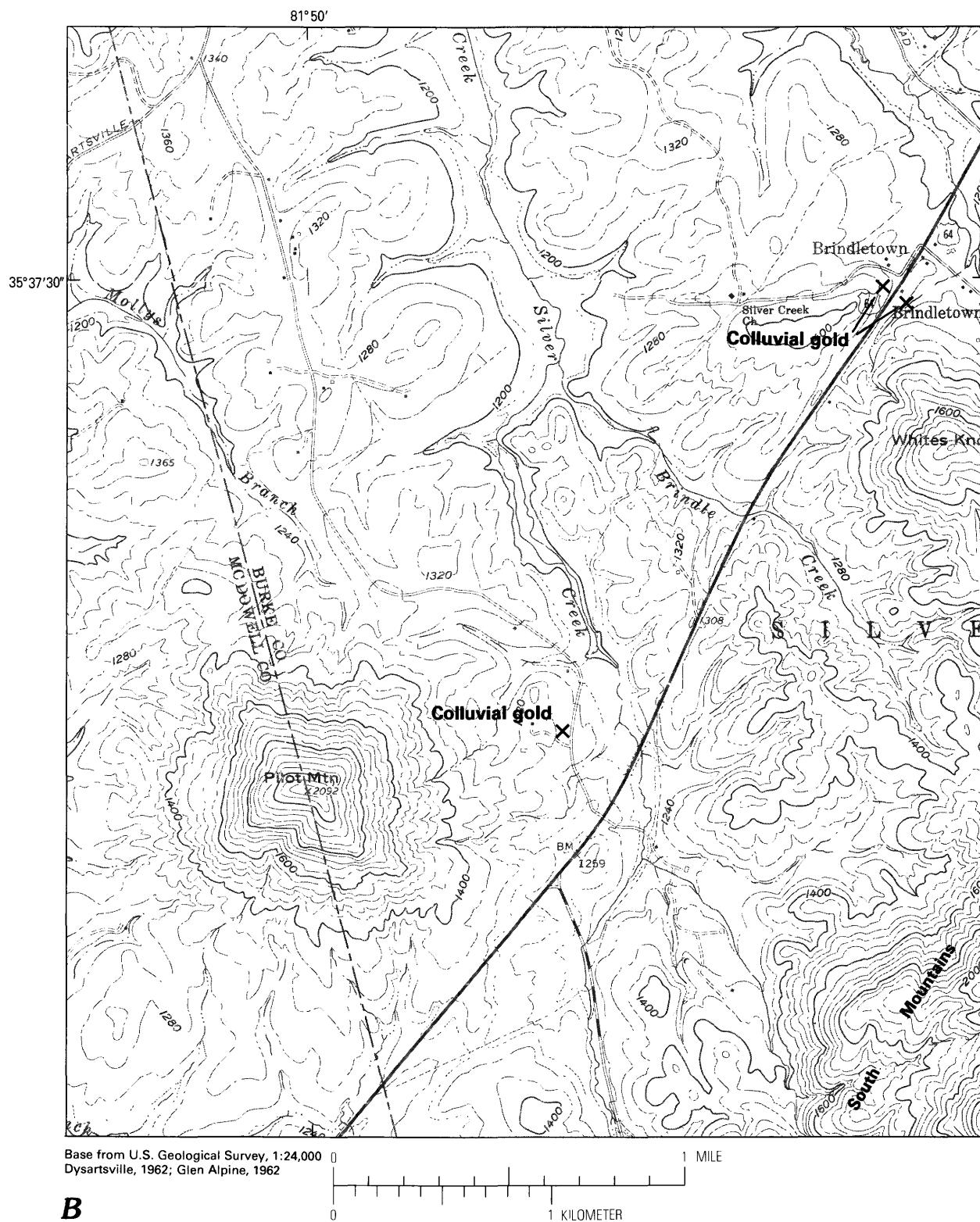


FIGURE 21.—Continued. *B*, Areas at and southwest of Brindletown.

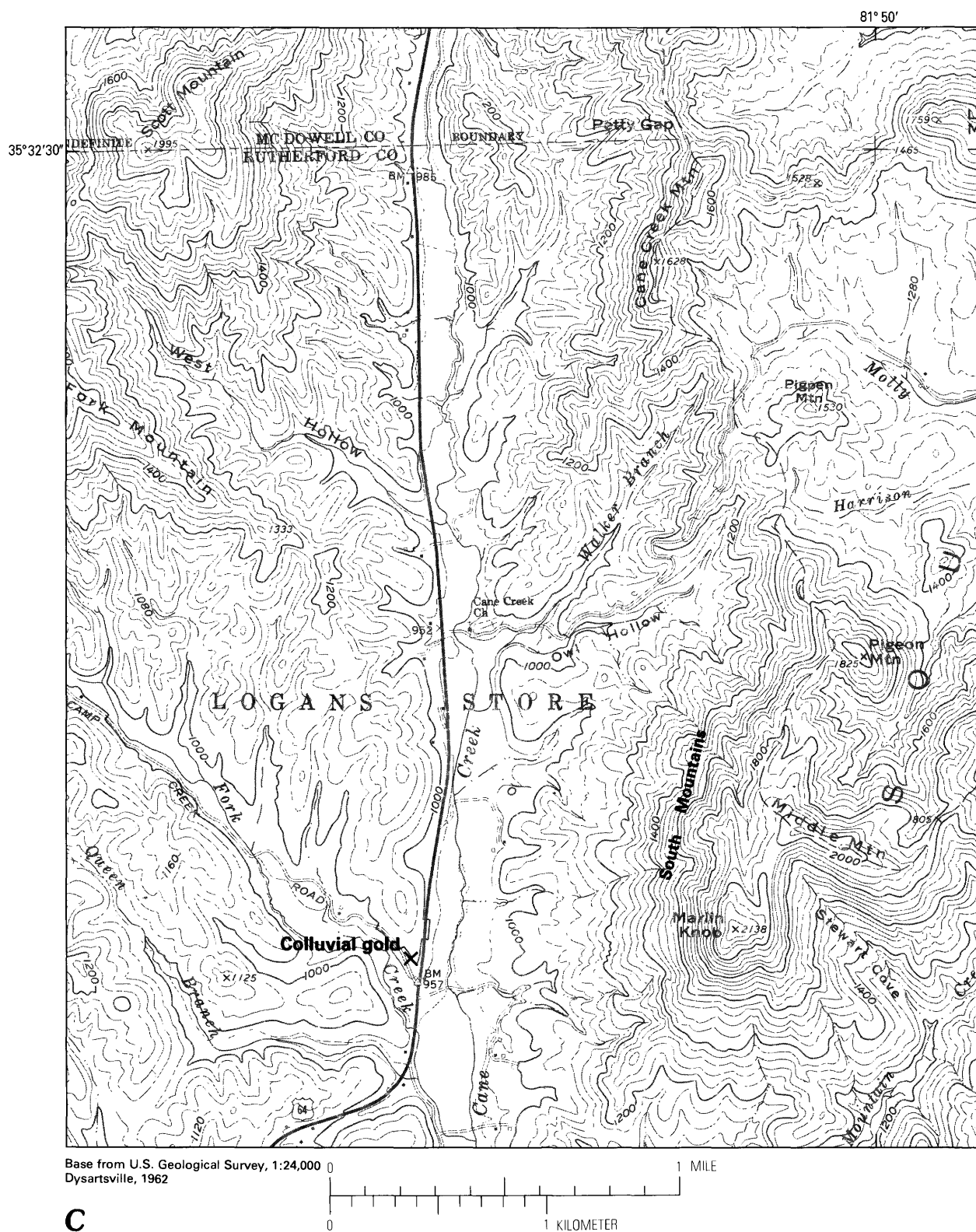


FIGURE 21.—Continued. C, Area in the southwestern part of the Dysartsville 7.5-minute quadrangle.

where sections 1 to 2 m thick can be seen on either side of the highway, and farther south on U.S. Route 64, 3.7 km south of the Rutherford County line, at the junction of Camp Creek Road, where a section 2 to 3 m thick can be seen at the northwest corner of the road intersection (fig. 21C). Gold also has been recovered by panning detritus from a roadside ditch located on the east side of Pilot Mountain, 5 km east of Dysartsville, N.C. This sample site is on the west side of Brackett's Road, 0.6 to 0.8 km north of U.S. Route 64 and 1.6 km north of the Burke County line (fig. 21B). There, within 22 m of a source bed of gravel-rich colluvium, four 14-in gold pans of "dirt" yielded 600 to 700 tiny flakes of gold weighing 0.189 g. Within 15 m of the source zone in the colluvium, about 80 percent of the gold flakes exceeded 0.2 mm in diameter, but at 22 m from the source, more than half of the flakes recovered were less than 0.2 mm in diameter.

RESOURCE POTENTIAL

Colluvial deposits, which we estimate to have gold grades averaging 1.55 g/m ton (.045 oz/short ton),¹ have

a high potential for a small volume of (gold) resources. Colluvium also may contain resources of zircon, which may be 2 to 3 times more abundant in colluvium than in stream sediments.² As much as 75 percent of some pan concentrates from colluvium over granite consist of zircon, estimated visually by using fluorescent light.

REFERENCE

- Gair, J.E., and D'Agostino, J.P., 1986, Mineral resource potential for gold in the Charlotte 1°×2° quadrangle, North Carolina and South Carolina: U.S. Geological Survey Miscellaneous Investigations Series Map I-1251-H, scale 1:250,000.

¹Grade calculated from amounts of gold recovered in individual pans of colluvial material from different locations, by using 9 kg as the weight of one pan of material. The large-scale recovery of gold from a colluvial deposit probably will yield some flakes of gold substantially coarser than commonly recovered in the individual pans of material.

²We estimated the average tenor of zircon in stream sediments to be about 1 g/kg of unwashed sediment.

GOLD IN FOSSIL PLACERS IN TRIASSIC SEDIMENTARY ROCKS OF THE WADESBORO BASIN

By JOHN P. D'AGOSTINO and SALLIE I. WHITLOW

GEOLOGIC SETTING

Native gold occurs in Triassic rocks of the Wadesboro basin near the southeastern corner of the Charlotte quadrangle and in rock older and younger than the Triassic near the Wadesboro basin (fig. 22; Gair and D'Agostino, 1986). This part of the quadrangle has had no

record of gold occurrences or mining for metallic minerals. During the present survey, however, native gold was found in sediments in nearly all streams in the area of the Wadesboro basin within the Charlotte quadrangle. Native gold was also found in many pan concentrates made from bulk samples of channel conglomerate that are enclosed by Triassic red siltstone beds (fig. 22A,B).

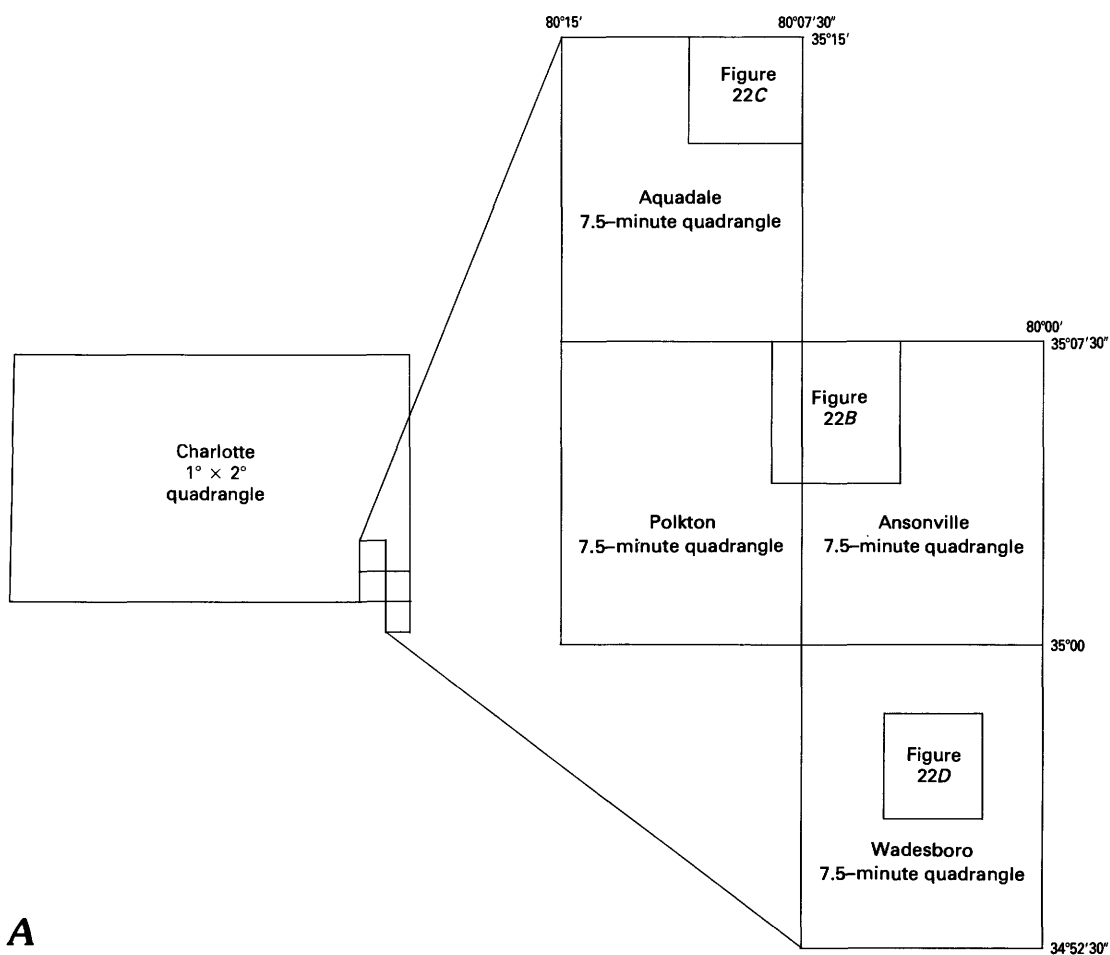


FIGURE 22.—Occurrences of gold in and near the Wadesboro Triassic basin in the Ansonville, Polkton, Aquadale, and Wadesboro 7.5-minute quadrangles within and adjacent to the Charlotte quadrangle. A, Index map.

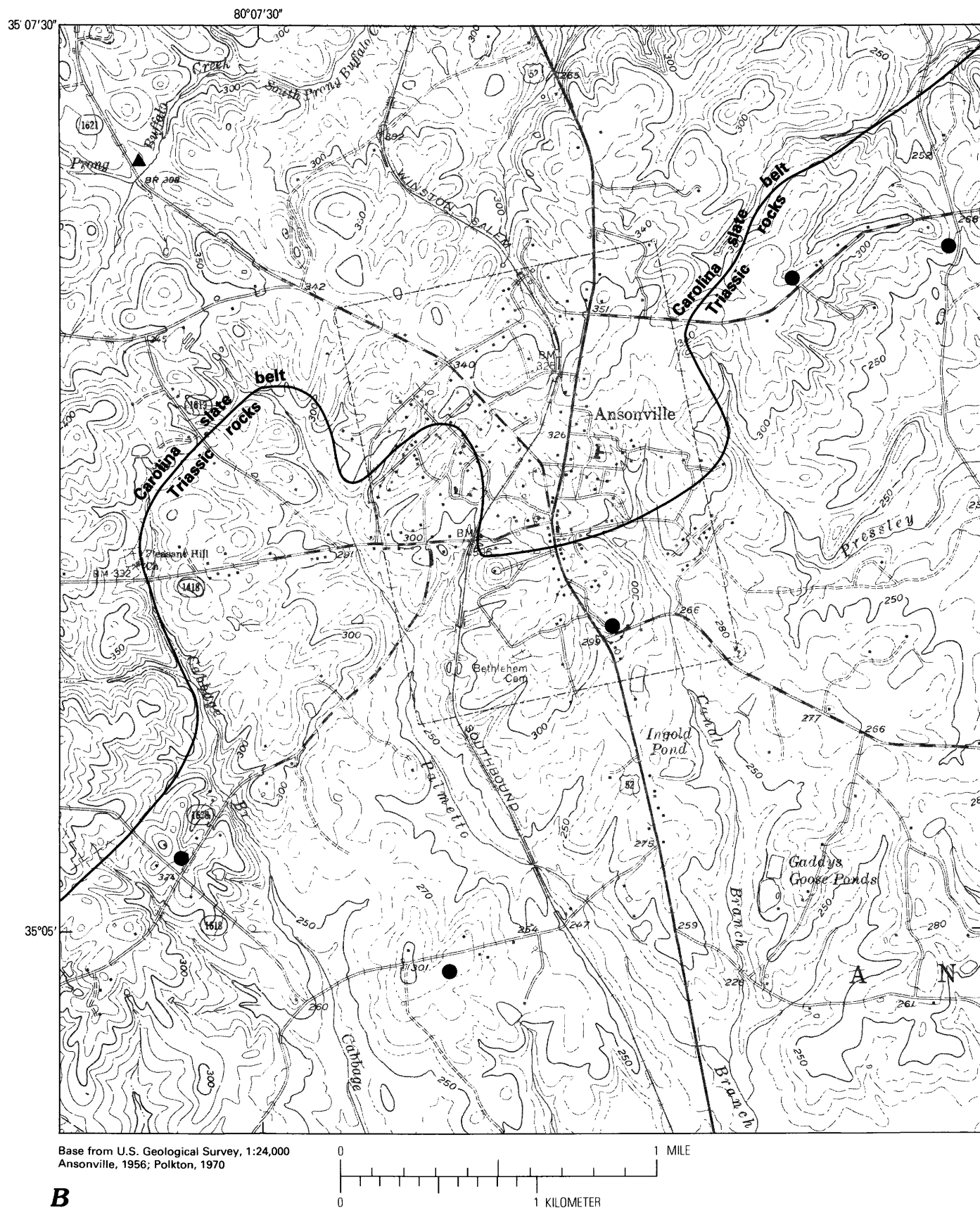


FIGURE 22.—Continued. B, Ansonville area. Triangle indicates gold in residual soil of the Carolina slate belt; circles indicate gold in Triassic conglomerate.

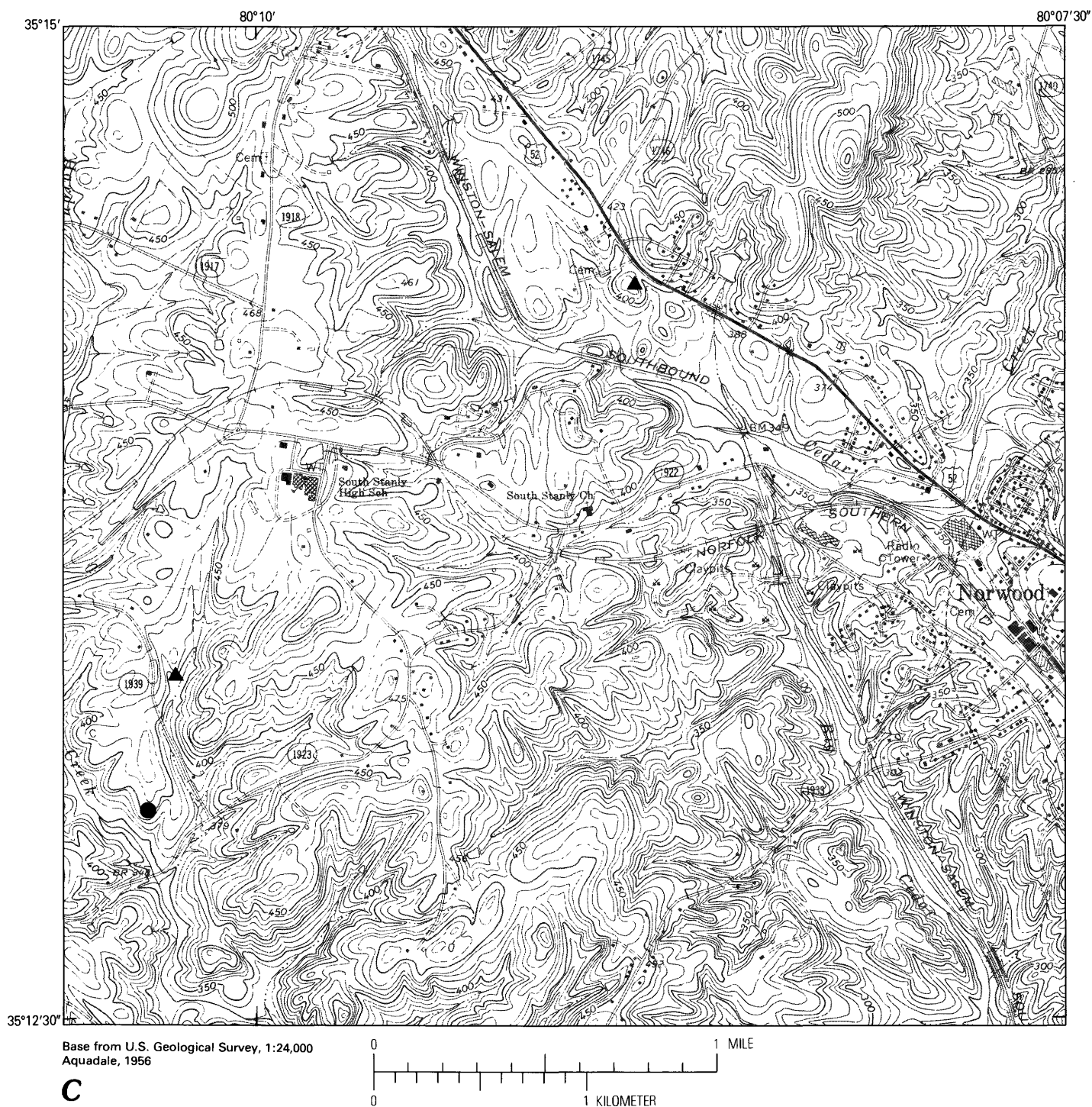


FIGURE 22.—Continued. C, Carolina slate belt near the Wadesboro Triassic basin (approximately 14 km northwest of the border of the basin). Triangles indicate gold in residual soil; circle indicates gold in upland terrace gravel overlying rocks of the Carolina slate belt.

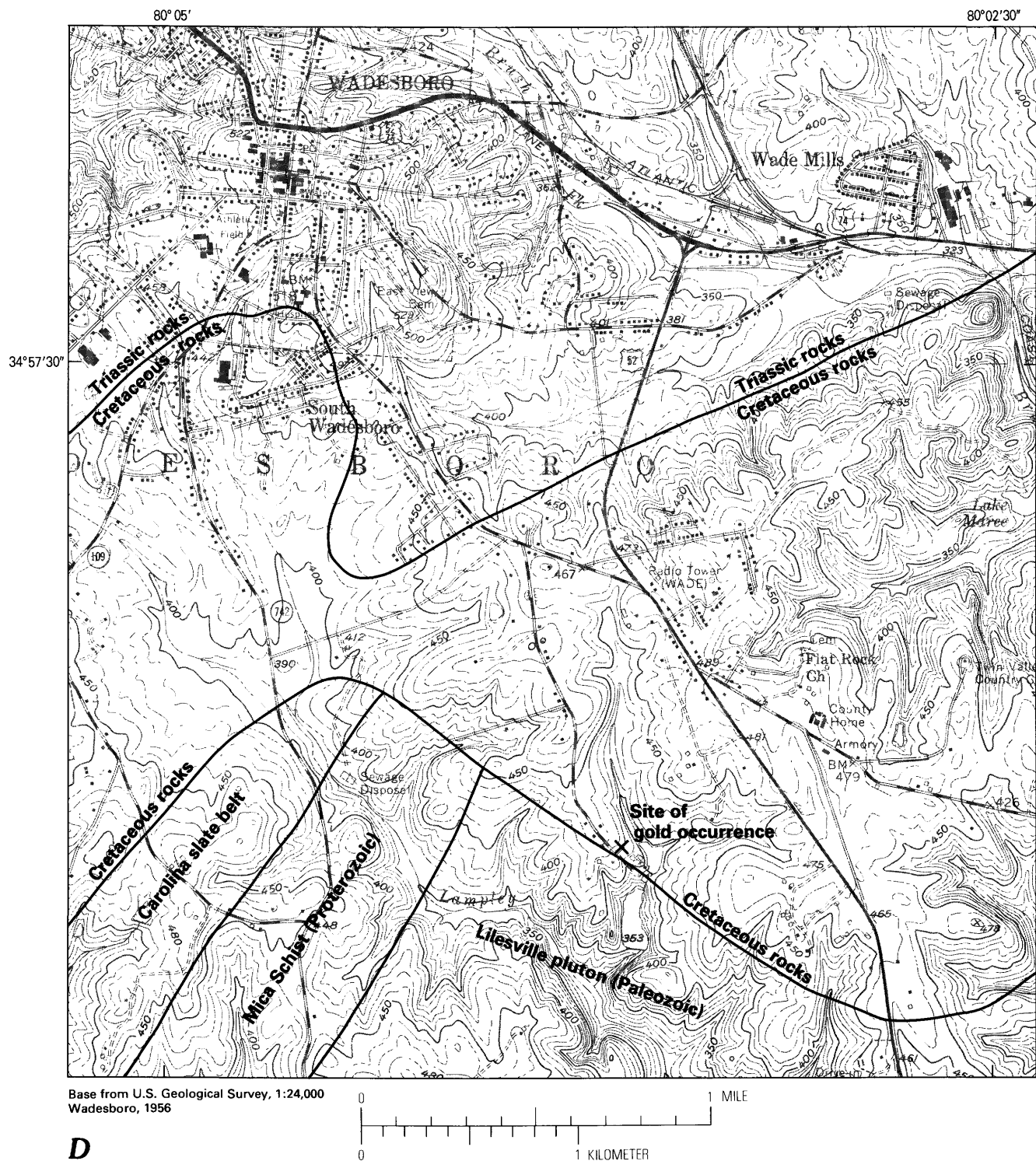


FIGURE 22.—Continued. D, Wadesboro area near the southeast border of the Triassic basin. X, site of gold occurrence in Upper Cretaceous gravels (Middendorf Formation) capping the Lilesville pluton.

The siltstones strike N. 35° E. and dip 30° SE., but the conglomerates evidently occur in channels that trend eastward. At one roadcut, a partially exposed channel conglomerate is about 1 m thick and more than 30 m wide. The conglomerate there consists mostly of gravel-to cobble-size quartz plus some slate and is probably flood derived. The conglomerate layer overlies a white clayey mudstone of unknown thickness. The white mudstone is associated with white quartz gravel and cobbles and is a key indicator of fossil Triassic channels in this area. The white material representing such channel deposits contrasts sharply with the usual brick-red, hematitic and limonitic, silty soils of the area. Each of several panned soil samples from five channel areas (fig. 22B) showed one to several flakes of nearly microscopic gold and a few specks of black hematite.

The northwest side of the Triassic basin is bounded by a border fault, adjacent to the Carolina slate belt. The rocks of the slate belt were probably the sources of some of the native gold in the Triassic channel conglomerates (fig. 22B,C). Other previously unreported native gold occurs just south of the southeastern corner of the quadrangle both in Triassic sedimentary rocks and just above the unconformable contact of Cretaceous Coastal Plain rocks with the underlying Mississippian Lilesville granite pluton (fig. 22D).

DESCRIPTIVE MODEL

Size of Triassic fossil gold placers

Length: Probably as much as several kilometers long.

Width: 25 to 100 m; maximum width, 200 m.

Thickness: Channel conglomerate at one roadcut, 1 m.

Lithology and geologic setting

Brick-red, well-bedded siltstone having abundant hematite-coated quartz grains. Further sampling of the poorly cemented fluviatile sediments of Mesozoic age is necessary to establish the characteristics of the unconformable gold-bearing contact zone between these sedimentary rocks and the Mississippian Lilesville granite.

Channel deposit characteristics

Large, elongated patches of white clayey soils, which contain or underlie white quartz gravels and cobbles, indicate the Triassic channels are as much as

200 m wide and trend eastward. Channel deposits are at least 1 m thick and several kilometers long. Known channel deposits are 2 to 4 km east from outcrops of the Carolina slate belt. Channel conglomerates generally are concealed by the associated red siltstone beds.

Mineralogy

The following minerals have been identified in stream sediments in the Triassic basin: quartz, native yellow gold, native white gold (electrum), ilmenite, magnetite, epidote, diopside, garnet, rutile, xenotime, topaz, cassiterite, pyrite, pyrrhotite, marcasite, chalcopyrite, and galena.

RESOURCE ASSESSMENT

Native gold in Triassic channel conglomerates is a newly discovered mode of gold occurrence in the area. The size of these channel deposits may be small to large. Information is needed on the number and spacing of this type of deposit and the dimensions, volume, and amount of retrievable gold available from individual deposits.

Minor amounts of native gold can be obtained from alluvium in streams of the Wadesboro basin and from the contact zone of the Lilesville granite pluton and the Mesozoic sediments.

The stream drainages of the Wadesboro basin in which gold has been found during this survey are considered to be areas of low to high potential for low-grade resources; the areas of higher potential are within the drainage basins containing occurrences of the white clay-conglomerate association. At best, the favorable zones are of low grade, so the potential for development will be strongly influenced by (1) the volume of gold-bearing material at a site, (2) its structural attitude, (3) its proximity to the surface, and (4) the degree of weathering, which affects the ease with which the overburden can be stripped and channel conglomerates mined.

REFERENCE

- Gair, J.E., and D'Agostino, J.P., 1986, Mineral resource potential for gold in the Charlotte 1°×2° quadrangle, North Carolina and South Carolina: U.S. Geological Survey Miscellaneous Investigations Series Map I-1251-H, scale 1:250,000.

FELDSPAR AND MICA PEGMATITES

By JACOB E. GAIR, WALLACE R. GRIFFITTS, J. WRIGHT HORTON, JR., and RICHARD GOLDSMITH

GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

Mining for mica has occurred in North Carolina during the last 115 years, whereas mining of feldspar for ceramic materials probably dates from colonial times. Most mica and feldspar were produced from granitic pegmatites. More recently, however, production of scrap mica and feldspar has come from saprolitized, coarse-grained granitic rocks. This production increased the number of deposit types and greatly expanded potential resources. Alaskite and other granite bodies commonly enclose productive pegmatites, and pegmatite and host rock may grade into one another. Other host rocks for pegmatites are mica schist, biotite gneiss, and amphibolite. Pegmatite in mica schist is the most likely source of white mica. Mica and feldspar commonly are recovered from the same pegmatite body, and one mineral typically is a byproduct of mining of the other. Most pegmatite sources of these minerals within the Charlotte quadrangle are in the Shelby-Hickory district of the Inner Piedmont (fig. 23), chiefly in Cleveland, Lincoln, and Catawba Counties. Low-grade scrap mica has been mined on a large scale from saprolitized granite pegmatite in Avery County in the Blue Ridge belt at the northwest corner of the quadrangle.

The mica recoverable from the pegmatites generally ranges from a few percent to about 10 percent; in local zones, the grade has been as high as 40 percent, although this is rare. The feldspar content of the pegmatites ranges from 25 to 50 percent. Silica and clays are possible byproducts of mica and feldspar mining.

There is no record of the early production of mica from the Shelby-Hickory district, once the major mica-producing area of the Charlotte quadrangle. Production from this district has been estimated to have been several million pounds (Griffitts and Olson, 1953). During World War II, 28,803 kg (originally reported as 63,481 lb) of trimmed sheet and punch mica were produced from the district.

The only mining during the early 1980's was along the southeast side of the Inner Piedmont in Cleveland County, where mica, feldspar, clay, and quartz were extracted from granite and pegmatite. The Kings Moun-

tain Mica Company and allied companies produced scrap mica, feldspar, silica (quartz), and clay from saprolitized and partly weathered Cherryville Granite extracted from pits located 5 km southwest of Kings Mountain, N.C. (Horton and others, 1981). In 1982, the Kings Mountain Mica Company and the Huber Corporation were independently exploring and drilling for new deposits of this type.

DESCRIPTIVE MODEL

Size and grade of pegmatites

Length: Less than 10 m to 160 m or more; shorter dikes more common in southwest part of area and larger dikes more common in northern part.

Width: 0.6 to 43 m; most are 1.5 to 3 m.

Depth: Up to 18 m known depth in southwest part of area; probably 60 m or more in northeast part of area.

Grades: Generally 2 to 10 percent mica; 25 to 50 percent feldspar.

Lithology of host rocks (major hosts for pegmatites)

Granitoid (monzogranite to quartz diorite); biotite gneiss; white-mica schist; sillimanite-mica schist; amphibolite.

Controlling structure or relation to nearby rock bodies

Most of the pegmatites in the central part of the Inner Piedmont trend east-west to northwest following tensional fractures and slip surfaces that are roughly parallel to the schistosity of the enclosing schists and gneisses. The schistosity and layering in the central part of the Inner Piedmont dip gently and form an irregular arcuate pattern transverse to the regional northeast trend of the Inner Piedmont belt as a whole. On the northwest and southeast flanks of the Inner Piedmont, where the schistosity and layering conform to the northeast regional trend, pegmatites also trend northeast.

Mineralogy

Major pegmatitic minerals: Perthite, muscovite, quartz, spodumene (common only adjacent to Kings Mountain belt and in the Hiddenite, N.C., area).

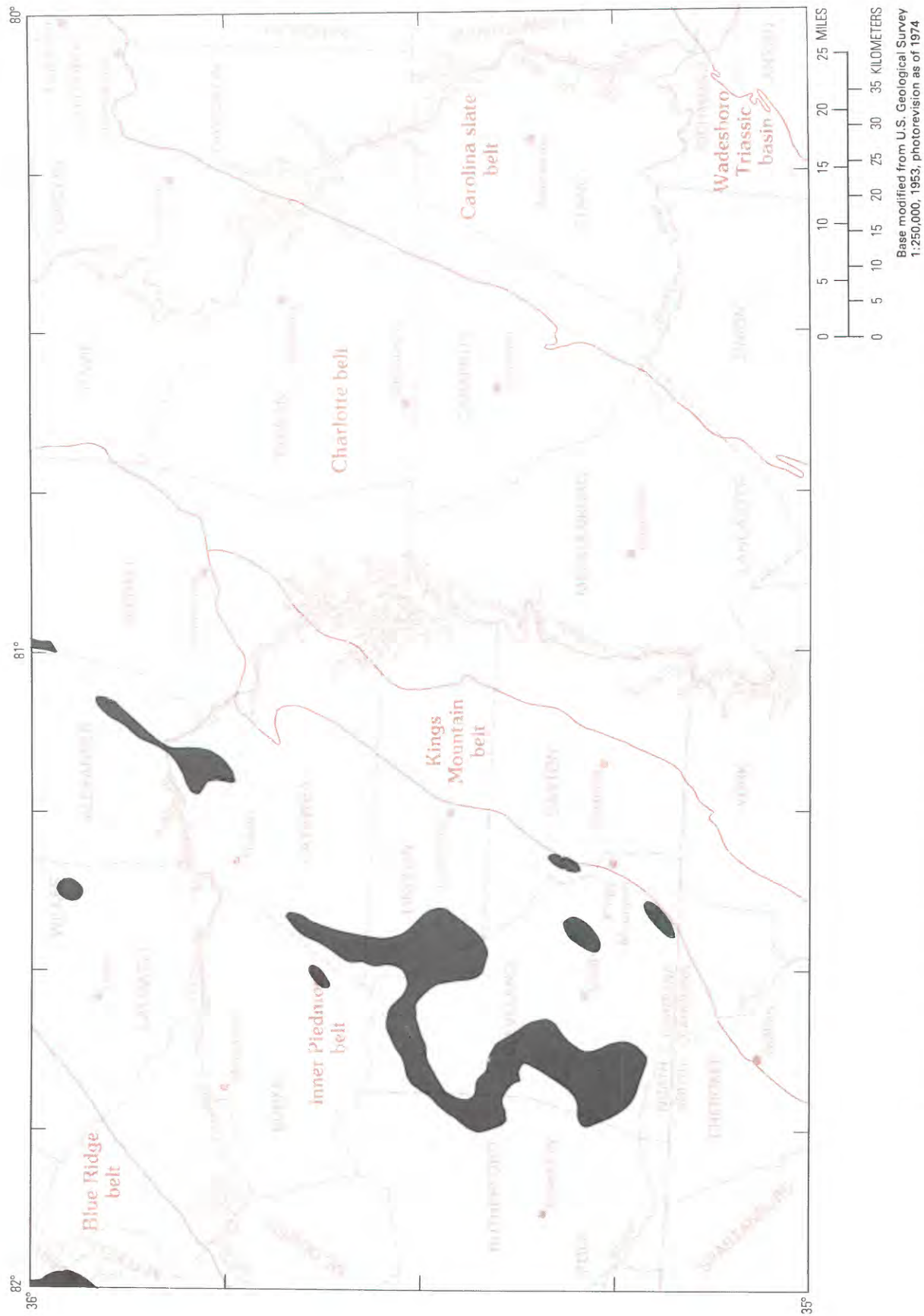


FIGURE 23. — Major areas of feldspar and mica resources in pegmatite (indicated by shading) in the Charlotte quadrangle.

Minor common pegmatite minerals: Albite, microcline, biotite, monazite.

Lesser pegmatite minerals: Beryl, tourmaline, cassiterite (in spodumene pegmatite).

Geochemical and mineral indicators

Coarse muscovite and (or) biotite and kaolin-rich zones in soil and saprolite; beryl or tourmaline in stream sediments.

Geophysical indicators

None.

Topographic indicators

Within areas of granitic plutons of Inner Piedmont belt, and especially near margins of Cherryville Granite, linear topographic lows may indicate pegmatite zones.

RESOURCE ASSESSMENT

Areas that are adjacent to production sites (see D'Agostino and Rowe, 1986) and that are within extensions of the known producing pegmatite bodies are areas of high potential for the occurrence of additional feldspar and mica resources. Other pegmatites, undeveloped and untested, constitute favorable geology. They have at least a low potential for feldspar resources and, if they contain more than 2 percent mica (mica pegmatite), also have a low potential for mica resources. The assignment of low potential for feldspar resources is based on the assumption of a typical feldspathic composition for the pegmatites and an absence of other favorable information; moderate or high potential could be assigned if there were evidence of adequate quality and quantity of the commodity, such as is implicit where there is a

history of production. There are many micaceous pegmatites and other pegmatites in the Inner Piedmont belt of the Charlotte quadrangle, especially near the margins of the Cherryville Granite bodies. Most of these pegmatites are too small to have been found or delineated on a 1:250,000-scale map during the CUSMAP survey.

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SPODUMENE IN LITHIUM-RICH PEGMATITES OF MISSISSIPPIAN AGE IN THE INNER PIEDMONT BELT

By J. WRIGHT HORTON, JR., and JACOB E. GAIR

GEOLOGIC SETTING, PETROLOGY, AND HISTORY OF DEVELOPMENT

Spodumene ($\text{LiAlSi}_2\text{O}_6$) is a major component of pegmatite dikes that occur in an elongate zone, at least 40 km long and 1 to 3 km wide, trending northeast from the South Carolina-North Carolina State line near Grover to Boger City, N.C. (fig. 24). This zone, originally called the "tin-spodumene belt" (Kesler, 1942), is located in the Inner Piedmont belt within 3.5 km west of the Kings Mountain shear zone, which constitutes the boundary between the Inner Piedmont and Kings Mountain belts (Horton, 1981; Goldsmith and others, 1988). Some dikes of spodumene pegmatite occur in the shear zone itself, and the shear zone may have influenced the emplacement of all the spodumene-pegmatite dikes (Horton, 1981). These pegmatites lie within 3 km east of the Cherryville Granite. Granite pegmatites that do not contain spodumene occur within and near the Cherryville and locally in gradational contact with spodumene pegmatite (Kesler, 1961, fig. 2; Kesler, 1976, p. 47). The Cherryville and both types of pegmatite are of Mississippian age (Kish, 1977). The belt of spodumene pegmatite in the Charlotte quadrangle contains the largest developed reserve of lithium in the world (Kunasz, 1976).

Spodumene was reportedly present but scarce in pegmatite drill cores from the Ross tin mine in Gaffney, S.C., 19 km southwest of the main belt of spodumene pegmatites (Kesler, 1961, p. 1063; Kesler, 1976, p. 48) (fig. 24). Pegmatites near the town of Hiddenite in Alexander County, N.C., that contain small amounts of gem spodumene are not related to those of the tin-spodumene belt in any obvious way.

The spodumene pegmatites are generally homogeneous, although compositional zoning occurs on a small scale. The average composition by weight is 20 percent spodumene, 32 percent quartz, 27 percent albite, 14 percent microcline, 6 percent muscovite, and 1 percent trace minerals (Kesler, 1961). Primary trace minerals include beryl (0.4 percent), manganapatite, zircon, ferrocolumbite, and cassiterite. Coarse-grained spodumene and microcline (both rarely longer than 30 cm) and minor muscovite (generally less than 2 cm across) are sur-

rounded by a granular matrix of fine- to medium-grained quartz and albite. Fractures in broken crystals of spodumene and microcline are filled with the albite-quartz matrix. Twisted flakes suggest that some of the muscovite crystallized early, and its unfailing presence seems to refute White's (1981) inference that the magma was exceptionally dry. Border zones, which extend less than a meter from wallrock contacts, contain little or no spodumene or microcline and are composed mainly of fine-grained albite and quartz and minor chlorite, muscovite, and pyrrhotite. Most spodumene pegmatites are massive, but some are internally deformed and have an augen-gneiss texture. Tabular zones of layered aplite occur locally within the spodumene pegmatite, particularly near and roughly parallel to wallrock contacts. They consist of alternating layers, not more than a few centimeters thick, of albite-quartz and quartz-spodumene-albite (Gordon Luster, 1976, unpub. data; furnished by Foote Mineral Co.). Coarse-grained, zoned pegmatites no more than a few meters thick occur locally as sharply bounded conformable layers in the aplite and as irregular pods in more homogeneous pegmatite. They are characterized by an outer zone of muscovite and apatite as much as 3 cm thick, a thicker intermediate zone of coarse euhedral spodumene (some of which is overgrown by microcline), and an inner zone of coarse subhedral microcline. Fractures in the microcline are filled with vermicular spodumene and muscovite (Luster, 1976, unpub. data). In addition to the primary pegmatite minerals, secondary hydrothermal minerals occur in joints and vugs and at wallrock contacts, and supergene minerals occur in the oxidized zone near the surface (White, 1981). Approximately 100 minerals have been identified in the Foote mine at Kings Mountain, N.C. (Marble and Hanahan, 1978; Hanahan, 1985).

Norton (1973), Kesler (1976), and Stewart (1978) have proposed genetic models for the origin of the Kings Mountain spodumene pegmatite by partial melting (anatexis) of lithium-bearing metasediments. The metamorphic grade (staurolite zone) at the level of emplacement of the dikes is too low for partial melting, so the pegmatite magmas must have traveled (along decreasing pressure-

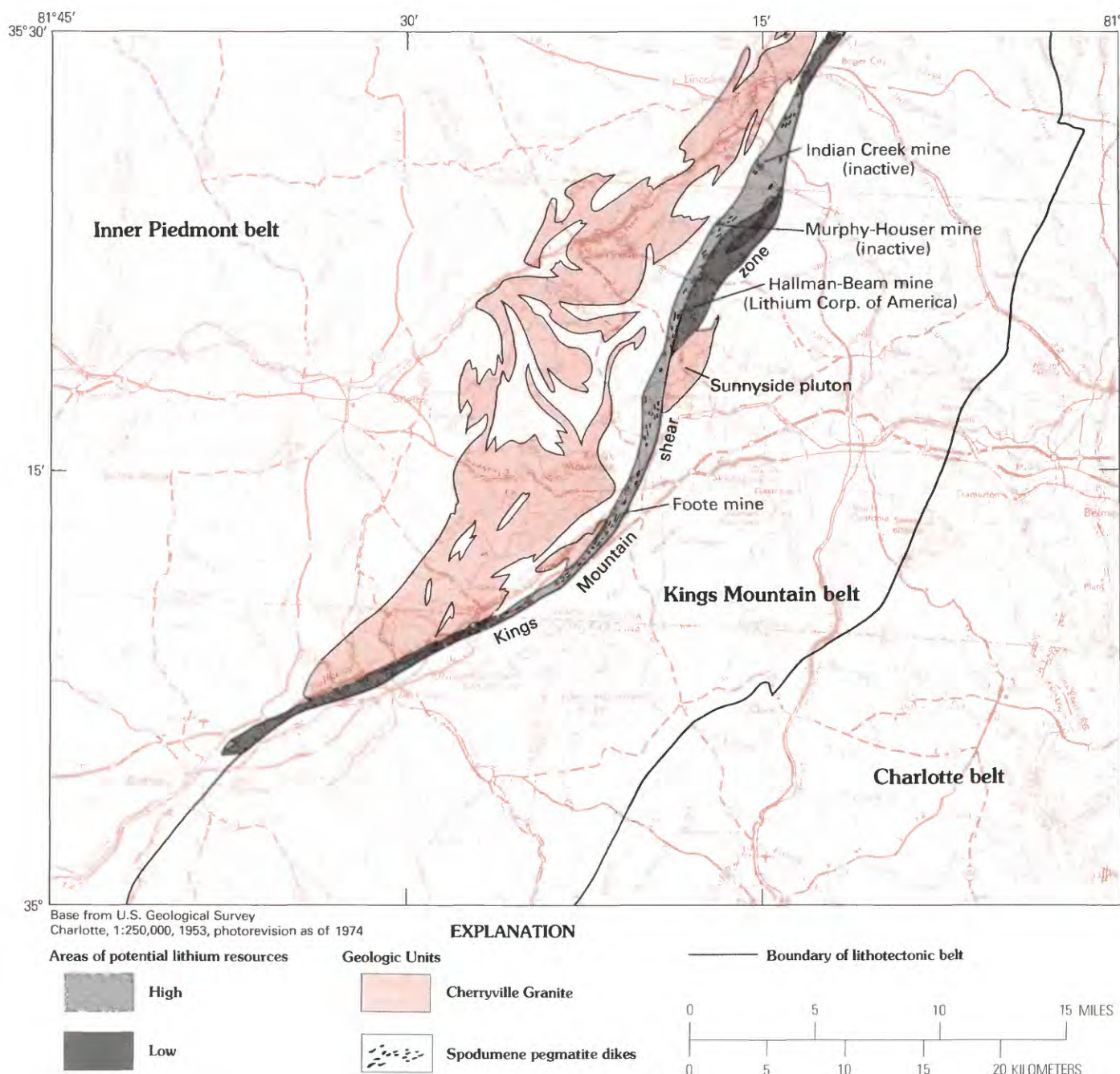


FIGURE 24.—Spodumene-pegmatite dikes in the south-central part of the Charlotte quadrangle. The two areas in which these dikes occur (light gray) are considered to have a high resource potential for lithium. Areas indicated by darker gray are considered to have low potential, on the basis of criteria discussed in the text.

temperature gradients). Norton (1973) noted that these pegmatites have the same composition as the first liquid to form during the melting of a feldspar-quartz-spodumene assemblage. Stewart (1978) showed experimentally that a melt of this composition could form at temperatures 75 °C or more below that at which granite melts (at the same partial pressure of H₂O). He pro-

posed a general model in which lithium-rich pegmatite magma forms at an earlier stage of the heating and melting that produces granite magma, in this case the Cherryville. Alternatively, spodumene pegmatite produced by crystal fractionation of a cooling magma could have the same composition. Stewart considered fractional crystallization superficially attractive as a mecha-

nism of lithium enrichment but unlikely because of the great volume of parent magma needed to produce even a small fraction of residual liquid having the appropriate composition.

A mechanism for lithium enrichment that has not been considered previously is liquid-state fractionation, as in the convection-aided "thermogravitational diffusion" model of Shaw and others (1976) and Hildreth (1979). Granitic magmas in the roof zones and margins of magma chambers can be enriched 10 to 20 times in rare lithophile elements over the bulk of the same granite and can already be sufficiently fractionated to crystallize lithium aluminosilicates, micas, or phosphates (D. London, written commun., 1982). Liquid-state fractionation supplemented by a separation of aqueous and silicate phases, as discussed by Jahns and Burnham (1969), is a viable alternative to the anatectic and simple fractional crystallization models.

The spodumene pegmatites were mined sporadically for cassiterite from 1903 until 1937, but total production probably did not exceed 110 short tons of metallic tin (Kesler, 1942). A USGS strategic minerals investigation begun in 1938 (Kesler, 1942) revealed that spodumene was potentially more important than cassiterite. The Solvay Process Company operated an open-pit spodumene mine and flotation plant 3 km southwest of the town of Kings Mountain, N.C., in the early 1940's (Kesler, 1961). This mine was inactive from 1945 until 1951, when Foote Mineral Company opened a still-active pit on the same property (Kesler, 1961). In 1955, the Lithium Corporation of America opened a lithium chemicals plant at Bessemer City, N.C., and began mining at the now inactive Murphy-Houser and Indian Creek mines near Lincolnton, N.C. Their present open pit, the Hallman-Beam mine 7 km northwest of Bessemer City, has been active since 1968 (Singleton, 1979). Total production in the area through 1978 is equivalent to 58,500 short tons of lithium metal (J.H. DeYoung, Jr., 1982, oral commun.).

As the alkali metal of lowest atomic weight, lithium is the metal of lowest density and is the most electrochemically reactive. Lithium compounds are used in aluminum reduction cells, in ceramics and glasses to improve thermal shock resistance, in lubricating greases effective over a wide range of temperatures, in refrigerants for air conditioning, in pharmaceuticals, and as a catalyst in the manufacture of synthetic rubber (Singleton, 1979). Lithium and its compounds also are used in nonrechargeable batteries. Spodumene is used directly in the manufacture of some glasses and ceramics. Potential new uses for lithium in rechargeable batteries and in the development of nuclear fusion as an energy source may greatly increase its consumption in the future (Hammond, 1976).

The major byproduct of spodumene mining in North Carolina is a feldspathic sand that contains 2 parts sodic feldspar and 1 part quartz; it contains some lithium and is used in the ceramic and glass industries (Singleton, 1979). Muscovite is a current byproduct, and quartz and feldspar have also been recovered. Amphibolite host rock from both mines is crushed as a byproduct by Martin Marietta Corporation for roadbase material. The pegmatites contain low-grade resources of beryllium (Griffitts, 1954), and a pilot plant was temporarily operated by the U.S. Bureau of Mines to test the recovery of beryl as a byproduct (Browning, 1961).

DESCRIPTIVE MODEL

Size and grade of spodumene pegmatites

Length: Dikes range from a few centimeters to almost 1,000 m in length; they are generally less than 250 m long. They occur chiefly in a zone about 40 km long. Additional dikes occur at Gaffney, S.C., 19 km southwest of the main pegmatite field.

Width: Dikes range from a few centimeters to about 90 m in width; they are generally less than 10 m wide. The pegmatite field is 1 to 3 km wide.

Depth: Drilling deeper than 200 m has encountered no change in pegmatite composition (Kesler, 1976). The deepest spodumene pegmatite confirmed by drilling was at 274 m (Engineering and Mining Journal, 1952).

Volume (tonnage): In 1976, after 16 years of mining, Foote Mineral Company announced proved reserves of 38 million short tons of spodumene pegmatite over approximately one-half of its property (Kunasz, 1976). Reserves on the remaining half were reportedly unknown. In the same year, the Lithium Corporation of America reported proved and probable reserves of 30.5 million short tons of spodumene pegmatite grading 1.5 percent Li_2O and 27.5 million short tons recoverable by open-pit mining (Kunasz, 1976). These known reserves total 68.5 million short tons of spodumene-pegmatite ore having an average grade of about 1.5 percent Li_2O . This is equivalent to 1,027,500 short tons of Li_2O or 477,000 short tons of lithium. A more recent assessment by the National Research Council (Evans, 1978) indicates 56.0 million short tons of proved or measured reserves and 9.3 million short tons of probable reserves of ore-grade spodumene pegmatite, mostly at the two active mines. Additional resources of ore-grade pegmatite outside of currently envisaged mining limits and in undeveloped parts of the spodumene-pegmatite belt to a depth of 1,500 m were statistically estimated at 795.5 million short tons (Evans, 1978).

Grade: The average grade of pegmatites at the Foote mine and at the Lithium Corporation of America's Hallman-Beam mine is essentially identical: 20 weight percent spodumene and 1.5 weight percent Li_2O (Broadhurst, 1956; Kesler, 1961, tables I and III; Kunasz, 1976). The average grade at the Lithium Corporation of America's Indian Creek mine (now inactive) was also 20 percent spodumene (Broadhurst, 1956). Spodumene percentages at the Foote mine have a normal distribution and a standard deviation of 4.2 percent in single samples and 2.1 percent in grouped samples (Stewart, 1978). At the Foote mine, 97.6 percent of the Li_2O is in spodumene that has an average Li_2O content of 7.46 weight percent compared with the theoretical 8.04 percent (Kesler, 1961, table I). In many dikes, 15 to 30 percent of the upper 30 m is weathered sufficiently to affect the grade of ore (Broadhurst, 1956). The limits on grade are important for prospecting and development, as well as for petrogenetic models (Stewart, 1978).

Lithology of host rocks and wall-zone alteration

The most common host rocks for spodumene pegmatite are white-mica schist and amphibolite. Pegmatite dikes intruded into schist are commonly tabular and approximately parallel to the steep schistosity. Those intruded into amphibolite are generally massive, more irregular, and discordant. Amphibolite is locally brecciated adjacent to pegmatite contacts. Amphibolite is altered to biotite schist within about 60 cm of the pegmatite contacts (Kesler, 1961). Holmquistite, a lithium amphibole, occurs in these alteration zones and is most abundant adjacent to the pegmatite. Kesler (1961) also noted the partial alteration of biotite to chlorite and associated sulfide mineralization within about 21 m of the pegmatites. Aplite dikes have been described at the Foote Mine, where two generations have been recognized (Horton and Simpson, 1978; Horton and others, 1981). The younger aplite dikes, unlike the older ones, contain trace amounts of spodumene, have chilled margins, and have biotite-rich contact aureoles in the amphibolite.

Controlling structure or relation to nearby rock bodies

The spodumene pegmatite dikes lie within 3.5 km of the Kings Mountain shear zone, which may have controlled their emplacement (Horton, 1981). They also lie within 3 km of the east side of the irregular Cherryville Granite pluton of Mississippian age, which may be genetically related. Kesler (1976, p. 47) described a 30-m-wide dike of pegmatite, 60 m east of the Cherryville, that grades eastward across its strike from simple granite pegmatite to spodumene-bearing pegmatite.

Mineralogy

Primary major minerals: Spodumene, quartz, albite, microcline, muscovite.

Primary trace minerals (<1 percent): Manganapatite, beryl, zircon, ferrocolumbite, cassiterite.

Secondary hydrothermal minerals in joints and vugs: Apatite, fairfieldite, switzerite, roscherite, lithiophilite, lithiophosphate, eosphorite, vivianite, tetrawickmanite, bikitaite, eucryptite, bertrandite, bavenite, milarite, brannockite, eakerite, swinefordite, tin-bearing titanite, rhodochrosite-siderite (White, 1981).

Supergene minerals: Birnessite, cryptomelane, gypsum, hydrated phosphates of manganese and iron (White, 1981).

Hydrothermal minerals at wallrock contacts: Holmquistite, biotite, tourmaline (schorl), pyrrhotite, garnet (spessartine-grossular), ferroaxinite, epidote-clinozoisite, albite, quartz (White, 1981).

Geochemical and mineral indicators

Spodumene, beryl, or cassiterite in stream sediments; tourmaline (schorl) in schist; high lithium, beryllium, niobium, or tin concentrations in C-horizon soils; detectable lithium in ground water (Price and Ragland, 1968). Geochemical maps of tin, beryllium, and niobium in stream sediments of the Charlotte quadrangle roughly outline the known spodumene-pegmatite belt and suggest that it may extend several kilometers farther northeast (Griffitts, Dutweiler, and others, 1985; Griffitts, Whitlow and others, 1985a,b).

Geophysical indicators

Unknown.

RESOURCE ASSESSMENT

In most of the models of mineral occurrence in this volume, the combination of favorable geology and known ore-mineral occurrence warrants classification of an area as one of high resource potential. In the case of lithium resources, favorable geology requires the presence of pegmatite that contains the ore mineral, spodumene, and spodumene occurs only in these pegmatites. Thus, all areas that contain spodumene pegmatite have favorable geology and are considered to have a high resource potential for lithium (fig. 24). Gaps between known occurrences and a projection of the spodumene-pegmatite zone to the northeast of the known occurrences are considered to have low potential; other areas have virtually no potential (Horton, 1987). A few areas having lithium geochemical anomalies (Griffitts and Hoffman, 1985) within the areas of low potential are designated as areas of moderate potential. Except for an

isolated occurrence at Gaffney, S.C., nearly all areas of high to moderate potential are in North Carolina (fig. 24; Horton, 1987).

Spodumene percentages were not considered in assigning resource potential, because the pegmatites generally are uniform in composition, but spodumene percentages should be important in evaluating specific pegmatites in areas of high potential. Other important considerations for further exploration include the size, shape, orientation, and distribution of spodumene-pegmatite bodies. Surface exposures do not necessarily reflect the volume of minable ore. In addition to trenching and drilling, geochemical soil surveys may be useful in delineating spodumene pegmatites where outcrops are sparse.

The Charlotte quadrangle contains virtually all the reserves of pegmatitic lithium in the United States and a large part of the world's reserves (Norton, 1973; Singleton, 1979). The proved and probable reserves of nearly 70 million short tons of spodumene pegmatite, grading about 20 percent spodumene or 1.5 percent Li_2O , probably can be increased substantially by an extensive exploration program. Byproducts include feldspar, quartz, mica, and crushed stone. Beryl, ferrocolumbite, and cassiterite also may be recoverable in small amounts.

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CASSITERITE IN TIN-BEARING PEGMATITES AND GREISENS OF THE INNER PIEDMONT BELT

By JACOB E. GAIR and J. WRIGHT HORTON, JR.

GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

The major tin mineral, cassiterite, occurs in tin-bearing pegmatites and greisens of the Inner Piedmont belt, in the so-called tin-spodumene belt along the southeastern flank of the Inner Piedmont, and at scattered localities to the west (fig. 25; Griffiths and others, 1985; D'Agostino and Rowe, 1986; Gair, 1986). Most of the tin-bearing pegmatite of the tin-spodumene belt is spodumene pegmatite and is described in section "Spodumene in lithium-rich pegmatites of Mississippian age in the Inner Piedmont belt." However, cassiterite also occurs in pegmatites that do not contain spodumene (Keith and Sterrett, 1917; Kesler, 1942). The tin-bearing spodumene- and mica-rich pegmatites along the southeastern flank of the Inner Piedmont are of Mississippian age and are probably genetically related to the Cherryville Granite (Kish, 1977). Cassiterite also occurs in coarse-grained quartz-muscovite rock (greisen), which occurs near pegmatite contacts. The greisens probably formed from the alteration of mica schist by fluids that evolved during a stage of pegmatite emplacement. Most greisen bodies are barren of tin; the cassiterite-bearing greisens are generally no more than 15 m long and 1 m thick (Kesler, 1942). Kesler considered cassiterite greisens to be the most common "commercial grade" deposits in the tin-spodumene belt, and they are probably major contributors of cassiterite, particularly coarse-grained cassiterite, to the placer deposits. Cassiterite was found in stream sediments west of the tin-spodumene belt during CUSMAP (D'Agostino and Whitlow, 1985), and greisens found in schistose country rock in the same area may be a source of the alluvial tin. In recent drilling in this area west of the tin-spodumene belt by Billiton Exploration USA, Inc., and Texasgulf Minerals and Metals, Inc. (Carr and Dean, 1984), cassiterite has been found in layers of hornblende-biotite gneiss and biotite gneiss and in feldspar-quartz-tourmaline rock ("leucosome") concordant with the gneiss.

Cassiterite was identified as early as 1883 from samples collected in the town of Kings Mountain, N.C., and it was produced in sporadic operations between 1903 and

1937 (Dabney, 1884, Kesler, 1942). Approximately 60 inactive mines and prospects are known in the 40-km-long, 1- to 3-km-wide zone of spodumene pegmatites, which extends from near Grover, N.C., to Lincolnton, N.C. (Kesler, 1942). The largest production, however, was at the Ross tin mine in Gaffney, S.C., 19 km southwest of the main belt of spodumene pegmatites. Spodumene was reportedly present but very scarce in pegmatite drill cores from the Ross mine (Kesler, 1961, 1976). The Ross mine included placer workings, many open cuts, and a shaft more than 40 m deep (Sloan, 1908). Estimates of production range from a little more than 25 to about 85 short tons of metallic tin (Kesler, 1942); the amount contributed by placer workings is unknown. In 1941, the Atlas Collapsible Tube Company of Chicago sank a 27-m shaft with crosscuts at the old Faires mine near the southern edge of the town of Kings Mountain, but it was abandoned without reaching a production stage. The same is true of work during 1941 and 1942 by the Ka-Mi-Tin Concentrating Company in the Jake open cut and in the Condon shaft, 3.5 km southeast of Lincolnton. The most recent activity was in 1944, when the Aurum Mining Company of Gastonia, N.C., produced 10 short tons of ore yielding 200 lb of tin concentrate from the Beaverdam Creek area of Gaston County (Murdock, 1950, p. 17). No production from the area west of the spodumene pegmatite belt has been reported.

DESCRIPTIVE MODEL (GREISEN)

Size and grade of cassiterite-bearing greisen zones

Length: Less than 1 m to about 30 m; most are less than 15 m.

Width: A few centimeters to about 1 m, averaging about 0.3 m.

Depth: Several shootlike bodies have been prospected to depths greater than their surface lengths. The deepest shaft at the Jones mine reached a depth of 53 m (Pratt and Sterrett, 1904). There is no evidence of change in grade or mode of occurrence with depth. The depth limit of relatively economical mining

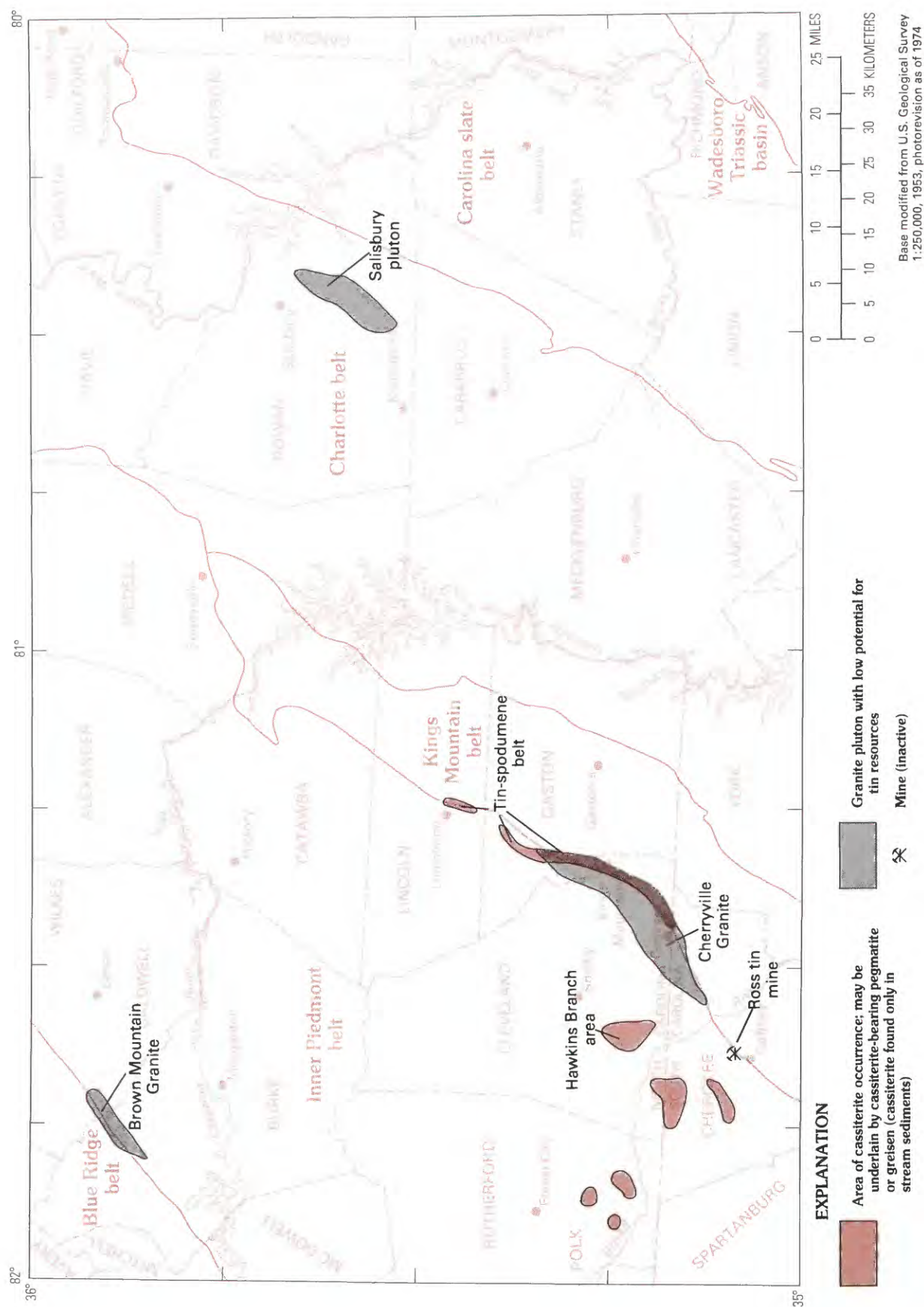


FIGURE 25.—Areas of cassiterite occurrence and other areas of potential for tin resources in the Charlotte quadrangle.

within the zone of weathering is assumed to be about 15 m in most places.

Volume (tonnage): Kesler (1942) estimated the 10 known deposits thicker than 0.3 m, but not yet mined below the zone of weathering, to contain about 188 short tons of metallic tin to a depth of 15 m.

Grade: The cassiterite content of ore bodies is variable. Metallic tin content ranges from less than 1 percent to more than 6 percent; Kesler's (1942) tonnage calculations were based on an assumed average grade of 1.5 percent tin.

Lithology of host rocks

Greisen occurs locally adjacent to pegmatite or in the vicinity of pegmatite bodies. Host rocks for greisen include white-mica schist and hornblende gneiss or biotite gneiss having layers of white-mica schist. Coarse recrystallized micas in greisen are generally parallel to foliation in the host rock but may have a more wavy orientation, or may in part grow across the foliation of the host rock.

Controlling structure or relation to nearby rock bodies

Pegmatite contacts are the most consistent structural controls, and the pegmatites are generally discordant with the foliation and layering in their host rocks. Locally, greisens are parallel to compositional layering, particularly where hornblende gneiss and white-mica schist are interlayered. Shears and joints may serve as structural controls in some cases.

Mineralogy

Quartz, muscovite, cassiterite.

Geochemical and mineral indicators

Cassiterite in heavy mineral concentrates; high tin values in analyzed samples.

Geophysical indicators

None.

DESCRIPTIVE MODEL (PEGMATITE)

No specific data are available about tin-bearing pegmatites in the Charlotte quadrangle apart from data about spodumene pegmatites that contain cassiterite in small amounts. Such data are incorporated in the model for spodumene pegmatite (see section on spodumene by Horton and Gair), and a corresponding tin- (spodumene-) pegmatite model is not presented here.

RESOURCE ASSESSMENT

Areas of high resource potential for tin are limited almost entirely to the narrow tin-spodumene belt, where there is a combination of favorable geology and numerous occurrences of cassiterite (Gair, 1986). Broad areas of

low resource potential occur over the Cherryville Granite pluton in the southeastern part of the Inner Piedmont belt and bordering parts of the Kings Mountain belt, northward to the end of the Kings Mountain belt, and across the southern part of the Inner Piedmont belt west from the Cherryville Granite almost to the quadrangle boundary. Low tin resource potential also is associated with rocks beyond the Inner Piedmont belt (the Salisbury granite pluton in the Charlotte belt and the Brown Mountain Granite in the Blue Ridge belt). At local geochemical anomalies for tin or tin-beryllium-niobium within these areas of low potential (Griffitts and others, 1985), the resource potential is classed as moderate (Gair, 1986). The zone along which cassiterite has been found in bedrock by private company drilling since the completion of the CUSMAP survey (Carr and Dean, 1984; not indicated in fig. 25) has high resource potential.

The volume of tin resources obtainable from these deposits is likely to be small because of the small size of tin-bearing greisens and the low grade of tin-bearing pegmatite bodies. Many small bodies, 0.3 m or less in thickness and probably less than 10 m in length, may be relatively rich in tin but are prohibitively small for development. Kesler (1942) estimated that the gross amount of tin in the tin-spodumene belt might be as much as 33 short tons per meter of depth, but the deposits are so small that they would be impractical to mine. He also identified 10 deposits thicker than 0.3 m and not yet mined to a depth of 15 m (the weathering depth cutoff for relatively economical mining), which he estimated might average 1 m in thickness and might contain 1.5 percent tin. These deposits, therefore, may contain about 188 short tons of metallic tin to a depth of 15 m, or about 12.5 tons per meter depth. Potential tin-bearing greisens west of the spodumene pegmatite belt also are probably small, but, if closely enough spaced in some areas, they may contain sufficient quantities of tin to warrant mining. Such deposits or stratabound tin-bearing "veins," such as found in recent private company drilling (Carr and Dean, 1984), probably contributed cassiterite to placers like those along Hawkins Branch southwest of Shelby, N.C. (D'Agostino and Whitlow, 1985; Griffitts and others, 1985; Gair, 1986). The spodumene pegmatites contain trace amounts of cassiterite (less than 1 percent) available as a potential byproduct.

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KYANITE AND SILLIMANITE IN HIGH-ALUMINA QUARTZITE OF THE BATTLEGROUND FORMATION, KINGS MOUNTAIN BELT

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GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

The Charlotte quadrangle contains large reserves of kyanite and much lower reserves of sillimanite. The only significant kyanite production has been from Henry Knob (fig. 26) in York County, S.C., which was worked in 1935 and from 1948 through 1969 (U.S. Bureau of Mines, 1936-1971). Henry Knob and three similar deposits in Virginia and Georgia account for nearly all the kyanite produced in the United States since 1950 (Espenshade, 1973). The Henry Knob deposit, and therefore the Charlotte quadrangle, yielded approximately 293,000 short tons of kyanite from 1950 through 1969 and 20,383 short tons of pyrite as a byproduct from 1960 through 1969 (U.S. Bureau of Mines, 1936-1971; J.H. DeYoung, Jr., 1982, oral commun.). In 1969, Commercialores, Inc., a division of Combustion Engineering, Inc., discontinued production at Henry Knob as the parent company increased production at Graves Mountain, Ga. (U.S. Bureau of Mines, 1971).

Kyanite (and sillimanite) occurrences similar to that at Henry Knob are widespread in the Kings Mountain belt of the Charlotte quadrangle (fig. 26; D'Agostino and Rowe, 1986; Horton, 1987). They are principally beds and lenses of high-alumina kyanite quartzite or sillimanite quartzite interlayered with quartz-sericite schist of the Battleground Formation (Goldsmith and others, 1988). Felsic to intermediate metavolcanic rocks also are interlayered with the quartz-sericite schist. The high-alumina quartzite consists mostly of quartz plus kyanite or sillimanite. Common accessory minerals include white mica, pyrite, rutile, and magnetite. The presence of kyanite or sillimanite is a function of essentially isochemical metamorphic conditions. A few beds of kyanite quartzite cross the sillimanite metamorphic isograd and become sillimanite quartzite. Some of the high-alumina quartzite probably formed by metamorphism of fine-grained silica and clay produced by hydrothermal alteration of volcanic or epiclastic material in hot springs or solfataras (Espenshade and Potter, 1960; Wise, 1975), as at Henry Knob, where kyanite-quartz rock is in thin conformable lenses separated from one another by

quartz-sericite schist and where pyrite averages about 7 percent of the kyanite-quartz rock. Other deposits, as in the vicinity of the Pinnacle in Gaston County, N.C., grade laterally into quartz-pebble metaconglomerate, which can be traced for many kilometers (Horton, 1981), and were probably formed by metamorphism of a mixture of aluminum-rich clay and quartz. Such material, rich in alumina, silica, and titania, may have been derived by erosion of weathered volcanic material or of hydrothermal silica and clay from solfataric centers (Espenshade and Potter, 1960). Therefore, the aluminous and siliceous protoliths of the kyanite (or sillimanite) quartzite probably originated by sedimentary processes in some cases and by purely hydrothermal processes in others.

Kyanite (Al_2SiO_5) and sillimanite (also Al_2SiO_5) are used in the manufacture of refractory materials. When heated sufficiently (calcined), both minerals convert to silica plus mullite, a stable refractory compound. Kyanite, unlike sillimanite, expands when heated, and the expansion is desirable in many applications to compensate for shrinkage of other materials such as binding clay (Hartley, 1976). Mullite refractories are used widely in the metallurgical industries, particularly in the steel industry.

Andalusite, another polymorph of Al_2SiO_5 , is equivalent to kyanite and sillimanite for most industrial purposes. Andalusite quartzite is found in the Charlotte belt (D.J. Milton, 1982, oral commun.), but grades and tonnages have not been evaluated. Hand samples from eastern Mecklenburg County, about 15 km east of Charlotte, N.C., contain as much as 30 percent andalusite. Isolated occurrences of kyanite quartzite and sillimanite quartzite, which resemble those of the Battleground Formation in the Kings Mountain belt, have also been found in the Charlotte belt (Privett, 1973).

DESCRIPTIVE MODEL

Size of kyanite or sillimanite ore bodies

Length: Continuous or semicontinuous layers of kya-

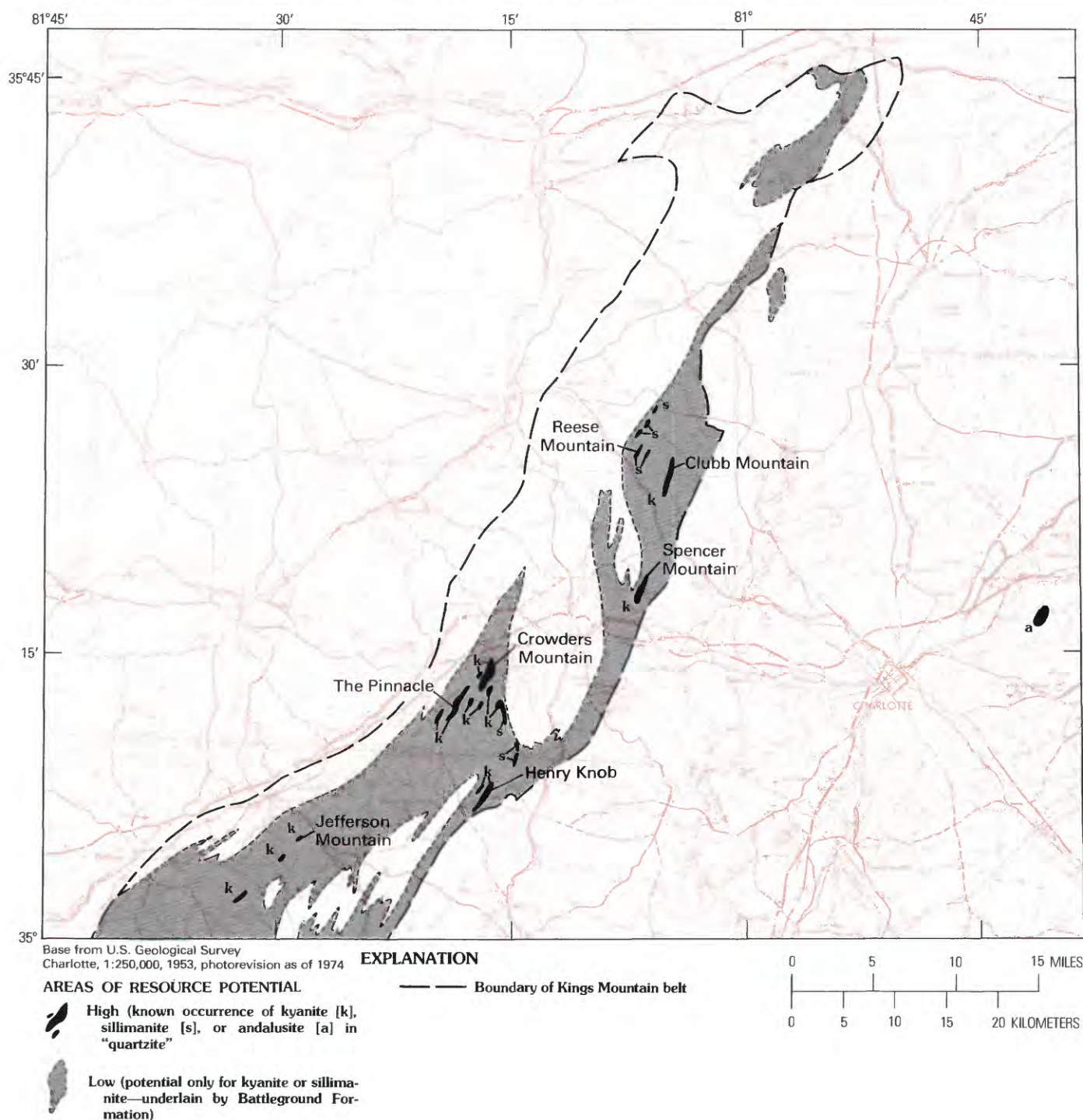


FIGURE 26.—Areas of resource potential for kyanite, sillimanite, or andalusite in high-alumina quartzite in the Charlotte quadrangle.

nite or sillimanite quartzite range in length from less than 100 m to about 3 km.

Thickness of width: Beds and lenses of kyanite and sillimanite quartzite typically range in thickness from 6 to 25 m. Thicker bodies occur at Henry Knob

(20 to 50 m) in York County, S.C., and at Crowders Mountain (30 to 140 m) and the Pinnacle (30 to 100 m) in Gaston County, N.C. Layers typically dip steeply (greater than 80°) so their surface widths closely approximate true thicknesses in most places.

Depth: Continuous segments of kyanite and sillimanite quartzite probably extend to depths about the same distance as their strike lengths, or less where dips are not steep. The larger deposits probably extend to depths of 1,000 m or more.

Volume (tonnage): Reserves of kyanite-quartz rock containing 10 to 30 percent kyanite and minable to depths of 15 to 60 m are estimated to be about 40 million short tons. Deposits of sillimanite quartzite containing about 30 percent sillimanite and minable to a depth of 30 m are estimated to be about 300,000 short tons (Espenshade and Potter, 1960).

Grade: The average ore at Henry Knob is about 28 percent (by volume) kyanite, 65 percent quartz, and 7 percent pyrite and minor amounts of rutile, white mica, and barite (Espenshade and Potter, 1960). White-mica schist interlayered with the quartzite contained enough kyanite (10 to 12 percent) to be mined with the quartzite (Smith and Newcome, 1951). Kyanite or sillimanite typically ranges from 5 to 35 percent (by volume) in the high-alumina quartzites. The abundance of pyrite at Henry Knob is unusual; most occurrences contain less than 1 percent pyrite.

Lithology of host rocks

The high-alumina quartzites consist almost entirely of quartz and kyanite or sillimanite, depending on the degree of metamorphism. They occur within the Battleground Formation as beds or lenses interlayered with quartz-sericite schist and lesser amounts of metavolcanic rock.

Types of associations with host rocks (mode of occurrence)

Kyanite occurs in the quartzite as blades or aggregates as much as 1 cm in length, is typically poikiloblastic, and has quartz inclusions near the edges of crystals. Forms include aligned and nonaligned crystals parallel to the foliation and crystals or radial clusters that cross the foliation. Kyanite-bearing quartz veins also have been observed, but only within kyanite quartzites, so kyanite may have been partly remobilized during regional metamorphism (Smith and Newcome, 1951; Espenshade and Potter, 1960). Sillimanite occurs in quartzite as coarse prisms as much as 4 mm in length and as radial or matted aggregates of fibrolite.

Controlling structure or relation to nearby rock bodies

Outcrop patterns vary in complexity as a result of multiple episodes of deformation. Beds of high-alumina quartzite are generally thickened in the hinge areas of folds and are commonly attenuated or dismembered on the limbs. Unusual concentrations of kyanite quartzite occur at the Pinnacle and at Crowders Mountain, where beds are thickened and

repeated by folding. A sillimanite isograd generally parallels the contacts of the High Shoals Granite. Sillimanite quartzites lie within a few hundred meters of the western contact of the High Shoals or within 2.5 km of the eastern contact (Horton, 1981).

Mineralogy (kyanite quartzite)

Major mineral: Kyanite.

Minor metallic minerals: Pyrite, rutile, magnetite.

Gangue: Quartz, sericitic white mica.

Trace minerals and sparse accessories: Zircon, apatite, barite, lazulite, pyrophyllite, dolomite, chloritoid, staurolite, andalusite.

Mineralogy (sillimanite quartzite)

Major minerals: Sillimanite, kyanite (locally).

Minor metallic minerals: Rutile, magnetite, pyrite.

Gangue: Quartz, white mica, diaspore.

Trace minerals and sparse accessories: Zircon, apatite, andalusite, biotite, lazulite, topaz.

Geochemical and mineral indicators

Unusual concentrations of kyanite or sillimanite in quartzite, saprolite, soil, or stream sediment; rutile in panned concentrates of stream sediment.

Geophysical indicators

Generally none.

RESOURCE ASSESSMENT

The Charlotte quadrangle contains about 40 percent of the identified and potential kyanite resources in the Southeastern United States (Espenshade and Potter, 1960). All of the high-alumina quartzites in the Kings Mountain belt are considered to have high potential for kyanite or sillimanite (fig. 26; Horton, 1987). Pyrite and rutile (Marsh and Sheridan, 1976) are potential byproducts. Because of available geologic map coverage and because high-alumina quartzites generally form conspicuous hills and ridges, it is likely that the major high-alumina quartzites have been discovered. A practical first step in evaluating known occurrences will be to map the distribution and percentages of kyanite, sillimanite, rutile, and pyrite in the rock and possibly in heavy-mineral concentrates from saprolite and soil. Areas underlain by the Battleground Formation (Goldsmith and others, 1988) are considered to have a low potential for kyanite and sillimanite (fig. 26). Other parts of the Kings Mountain belt are considered to have virtually no potential for kyanite or sillimanite. Geochemical and heavy-mineral reconnaissance maps have little value in identifying new areas of moderate to high potential because of the widespread occurrence of these minerals (W.R. Griffiths, 1982, oral commun.).

Urbanization of presently rural and undeveloped areas around Gastonia, N.C., is rapidly preempting the potential kyanite and sillimanite deposits. Clubb Mountain, for

example, is now a residential subdivision. The Pinnacle and Crowders Mountain, two of the largest and richest occurrences of kyanite quartzite, lie partly within Crowders Mountain State Park, N.C., and long-range plans for park expansion include most areas of high resource potential.

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SILLIMANITE IN SCHIST OF THE INNER PIEDMONT BELT

By J. WRIGHT HORTON, JR.

GEOLOGIC SETTING

An area of sillimanite occurrences in the Inner Piedmont belt, the so-called Cliffside-Elkin belt (Hunter and White, 1946), coincides essentially with a region of sillimanite-grade metamorphism. The host rock, sillimanite-mica schist that typically contains 5 to 20 percent sillimanite, underlies hundreds of square kilometers in the Charlotte quadrangle (fig. 27; Goldsmith and others, 1988). Little is known about the size and grade of sillimanite deposits, and a comprehensive descriptive model has not been developed. Sillimanite in quartzite of the Kings Mountain belt, another deposit type, is discussed in the previous section by Horton.

The sillimanite-mica schist is composed principally of sillimanite, muscovite, quartz, biotite, and garnet in varied proportions. Common accessory minerals include pyrite, graphite, chlorite, rutile, ilmenite, hematite, and zircon. The sillimanite commonly is partly altered to sericite, which is locally recrystallized to coarser muscovite. Needlelike crystals of sillimanite are disseminated in the schist and locally are concentrated in layers. Aggregates as much as 1 cm in length are common, and nodular lumps of sillimanite as much as 60 cm across were reported by Hash and Van Horn (1951). Zones of sillimanite-mica schist are as much as several kilometers in width and several tens of kilometers in length. Complex folds are common. Interlayered with the sillimanite-mica schist are subordinate amounts of biotite gneiss, quartz-mica schist, calc-silicate rock, and pegmatite.

Sillimanite-mica schist typically crops out on low ridges, and sillimanite float generally is abundant even where outcrops are scarce. Widespread float does not necessarily indicate a large deposit, however, because zones of schist rich in sillimanite may be interlayered with barren zones.

Reconnaissance surveys of sillimanite in heavy-mineral concentrates from stream sediments (Overstreet

and Griffiths, 1955, fig. 1), soils, and saprolite should define areas where coarse-grained sillimanite is unusually abundant. Detailed geologic mapping of these areas with information on percentages of sillimanite, its grain size, and degrees of sericitization may identify potential deposits worthy of more intensive exploration.

Hash and Van Horn (1951) described several sillimanite occurrences and made beneficiation tests on samples from the more promising localities. Sillimanite was difficult to separate from most samples because of fine grain size, sericitic alteration, mica intergrowths, and iron oxide coatings. Potential deposits at Smith Cliff in Burke County (5 to 7 percent sillimanite), Dudley Shoals in Caldwell County (16 to 32 percent sillimanite), and Wards Creek in Cleveland County (28 to 30 percent sillimanite) (fig. 27) contain unsericitized sillimanite crystals large enough for refractory use. Beneficiation tests reveal that sillimanite in samples from Smith Cliff and Dudley Shoals is stained with iron oxide, and its removal requires grinding too fine for conventional refractory applications. A very high grade but fine-grained (minus 100-mesh) sillimanite concentrate can be produced from almost any unsericitized sillimanite schist in the area (Hash and Van Horn, 1951).

RESOURCE ASSESSMENT

The Dudley Shoals, Smith Cliff, and Wards Creek areas (fig. 27), which contain unsericitized sillimanite crystals large enough for refractory use, have a moderate potential for containing sillimanite resources. Too little is known about grain-size distributions and degrees of sericitization for other areas of moderate potential to be defined. All areas of the Inner Piedmont underlain by sillimanite-mica schist are considered to have a low potential for sillimanite resources (fig. 27). The creation of a market for fine-grained sillimanite or a beneficiation process for removing iron-oxide stains would greatly increase the areas of moderate to high potential.

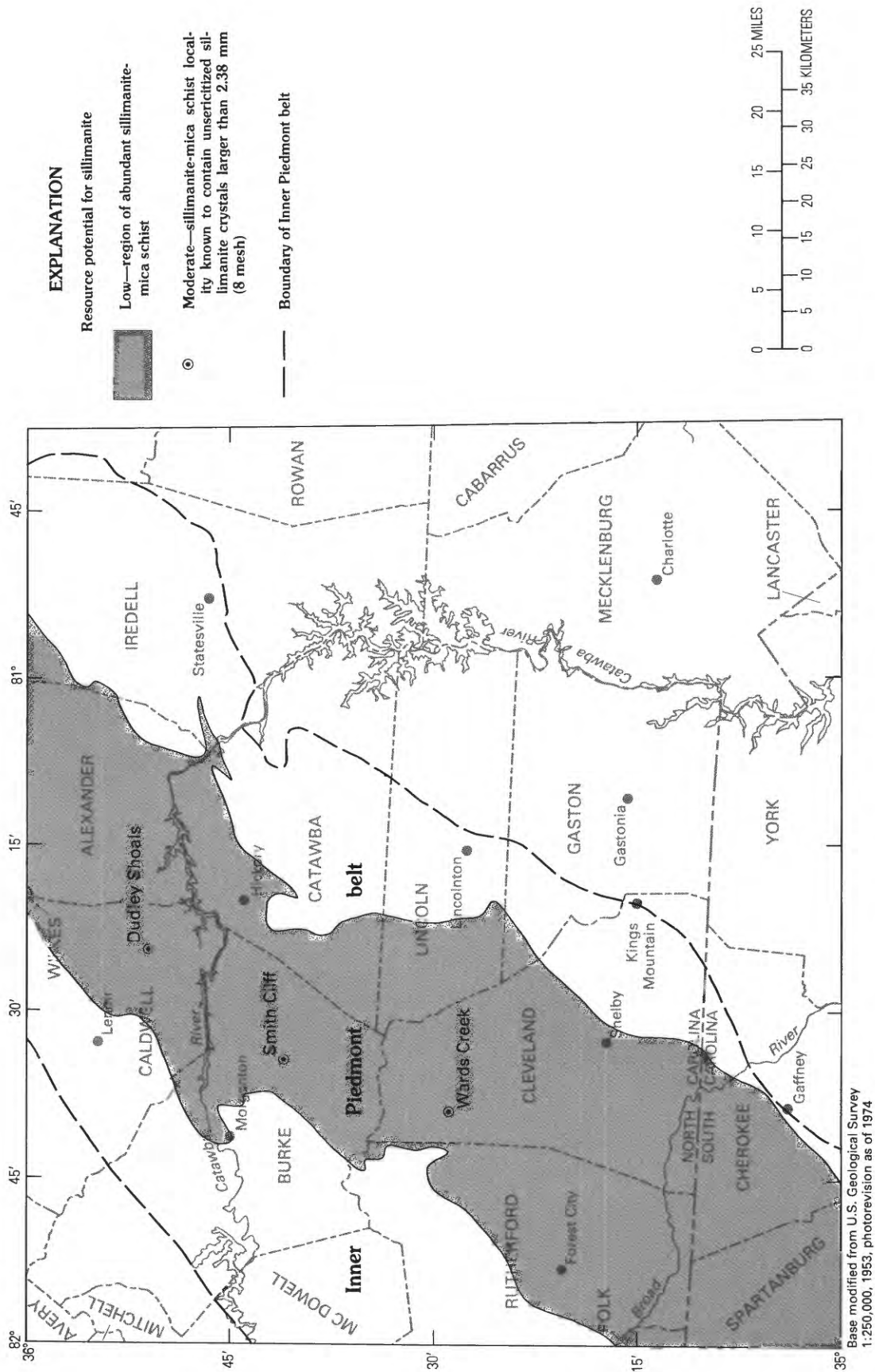


FIGURE 27. — Areas of resource potential for sillimanite in schist of the Inner Piedmont belt in the Charlotte quadrangle.

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BARITE IN QUARTZ-SERICITE SCHIST AND SCHISTOSE PYROCLASTIC ROCK OF THE BATTLEGROUND FORMATION, KINGS MOUNTAIN BELT

By J. WRIGHT HORTON, JR.

GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

Barite was discovered in the Charlotte quadrangle in the early 1880's (Van Horn and others, 1949, p. 9). The earliest production was in 1885 from small open pits at Kings Creek, Cherokee County, S.C. The Kings Creek deposit was worked almost continuously from 1885 until 1966 (Sharp and Hornig, 1981). It is within the north-northeast-trending Carolina barite belt. This zone of barite occurrences is about 40 km long and 3 km wide and extends from southeast of Gaffney, S.C., to Crowders Mountain, N.C. (fig. 28; D'Agostino and Rowe, 1986; Horton, 1987). It lies entirely within the Kings Mountain lithotectonic belt. Twenty-four barite localities were reported in the zone (Keith and Sterrett, 1931; Van Horn and others, 1949; Hornig, 1973). With a total production of about 433,000 short tons, the Carolina barite belt ranks third in the Southeastern United States in total production and resource potential, behind the Cartersville district of Georgia and the Sweetwater district of Tennessee (Brobst and Hobbs, 1968).

The barite deposits occur within the Battleground Formation (Goldsmith and others, 1988) in host rocks of quartz-sericite schist, derived at least partly from epiclastic and reworked pyroclastic material, and in schistose pyroclastic rock. The zone of occurrences is roughly but not precisely conformable with mapped rock units. Massive barite (80–90 percent BaSO_4) occurs in layers and pods that are typically about 30 cm thick but that range in thickness from a few centimeters to 3.7 m (Wilson, 1958; McCauley, 1962). They are either foliated or nonfoliated and concordant or discordant with the host-rock schistosity (Watkins, 1915; Van Horn, 1949; Sharp and Hornig, 1981). Sets of subparallel en echelon veins as much as 1.3 km in length were reported by Hornig (1973). Some veins contain coarse barite intergrown with quartz. Barite also occurs as scattered nodules as much as several centimeters in diameter and as impregnations in schist where barite concentrations range from less than 10 percent to more than 50 percent

(Wilson, 1958). Barite concentrations in the schist increase with proximity to the veins and pods of massive ore.

Chemical and isotopic data suggest a volcanogenic or hydrothermal origin for the barite (Goldberg and others, 1969; LeHuray, 1982). The barite conformable with stratigraphic units may have originated from sea-floor hot springs syngenetic with volcanism and sedimentation in the Kings Mountain belt, but it was probably redistributed and locally concentrated in discordant veins during regional metamorphism. Interlocking boundaries between barite, quartz, galena, and sphalerite grains suggest that all were recrystallized during metamorphism (Posey, 1981).

Before passage of the Pure Food and Drug Act in 1923, most of the barite from Kings Creek was used as a weighting agent in flour and sugar (Wilson, 1958). In subsequent years it was used as an industrial filler. Production of barite at Kings Creek ceased in 1966 when a new plant was built and emphasis shifted to crushing and storing imported colemanite (Sharp and Hornig, 1981). The open pits are still active (1983) but produce only white saprolite, derived from feldspathic quartz-sericite schist, for brick manufacture.

Barite is still a common filler and weighting agent because it is heavy, nonabrasive, and chemically inert. Most of the barite currently produced in the United States is used as drilling mud in the oil and gas industry. It is also used in the manufacture of glass to add brilliance and clarity, in the paint and rubber industries as a pigment and filler, and in the production of barium chemicals (Brobst and Hobbs, 1968).

DESCRIPTIVE MODEL

Size of barite veins and zone of barite occurrences

Length: Barite veins and pods can be as much as 915 m in length (Van Horn and others, 1949; Hornig, 1973); sets of closely spaced en echelon veins can be as much as 1.3 km in length (Hornig, 1973). Zone of barite occurrence is about 40 km long.

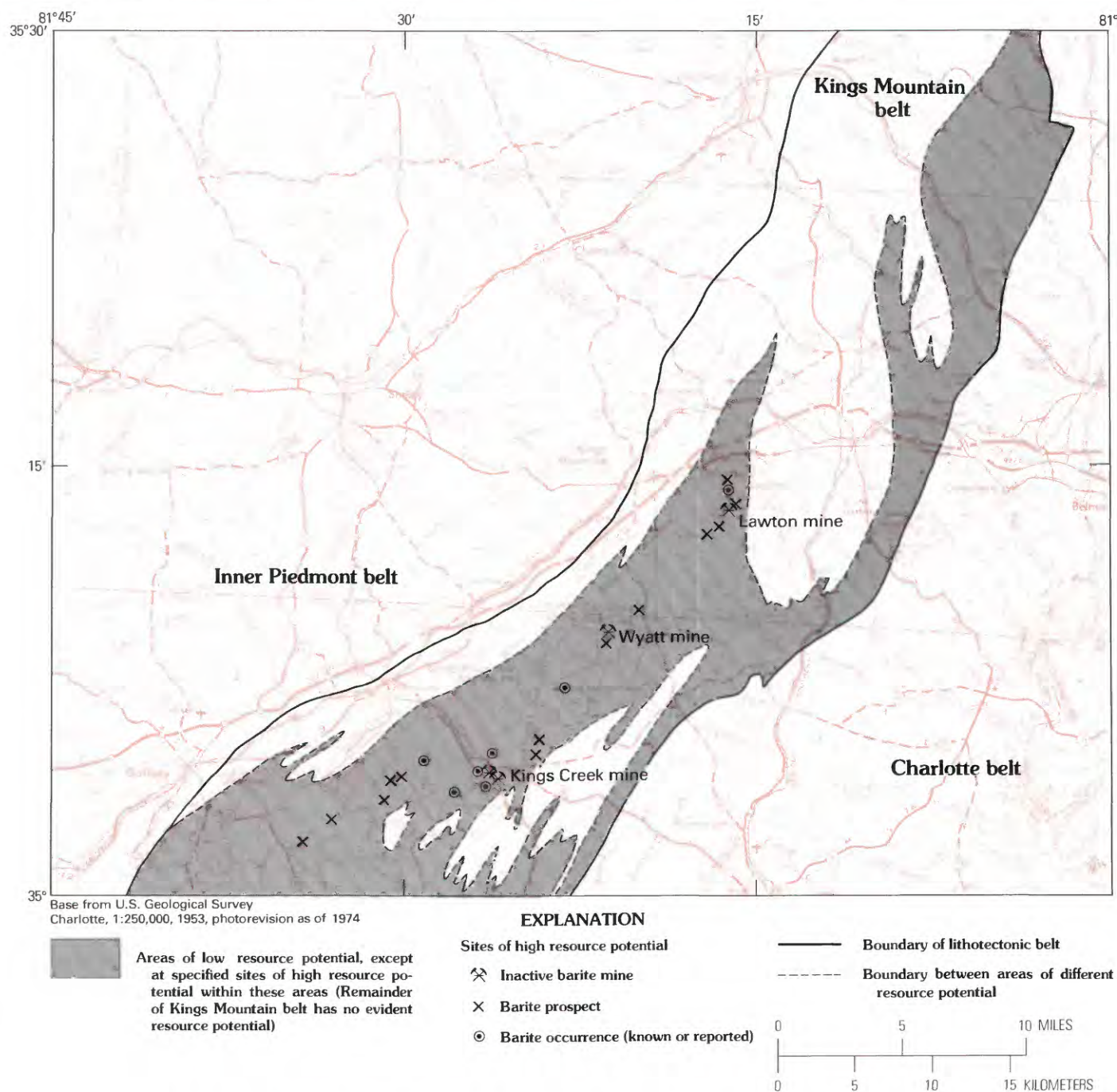


FIGURE 28.—Areas of resource potential for barite in the Kings Mountain belt in the Charlotte quadrangle.

Thickness or width: Veins and pods are 10 cm to 3.7 m thick; average thickness is about 30 cm (Wilson, 1958; McCauley, 1962). Zone of barite occurrence is about 40 km long.

Depth: Maximum depth of underground workings is about 60 m (Van Horn and others, 1949). Vein barite in drill cores from a depth of 76 m is reportedly identical to surface material (Van Horn and others,

1949). Veins probably extend to depths about the same as their strike length, or less where dips are not steep. Discontinuous layers and pods having dimensions similar to those at the surface probably occur along projections of the zone of surface occurrence to depths of 1,000 m or more.

Volume (tonnage): The largest single pod mined at Kings Creek produced about 30,000 short tons of barite.

The Kings Creek mine produced about 400,000 short tons of barite from 1910 to 1953, after which it was completely converted to open-pit mining (Wilson, 1958), and about 32,800 short tons from 1953 to 1966 (J.H. DeYoung, Jr., oral commun., 1982). Kings Creek accounts for nearly all of the barite produced in the Carolina barite belt. The Wyatt mine in Kings Mountain State Park, York County, S.C., reportedly produced about two carloads of hand-cobbed barite (Van Horn and others, 1949). Most of the material from the Lawton mine on Crowders Mountain, Gaston County, N.C., is probably still on the dumps. These dumps contain about 25,000 short tons of material containing 40 percent barite (Van Horn and others, 1949). Barite reserves at the Kings Creek mine probably exceed 500,000 short tons. Reserves of the entire belt are unknown but probably exceed 1 million short tons.

Grade: Massive barite in veins and pods is typically 80 to 90 percent BaSO_4 . Concentrations in impregnated schist range from less than 10 percent to more than 50 percent.

Lithology of host rocks

Quartz-sericite schist is probably derived from epiclastic and reworked pyroclastic material. The 40-km-long zone of barite occurrences lies within the Battleground Formation (Goldsmith and others, 1988), just east of a zone of high-alumina quartzite on the west limb of the South Fork antiform.

Types of associations with host rocks (mode of occurrence)

Although roughly stratabound, much of the barite is in veins and was probably redistributed during regional metamorphism. Associations include veins or pods of massive barite, small scattered nodules, and impregnated schist having variable barite concentrations (Wilson, 1958).

Controlling structure or relation to nearby rock bodies

Zone of barite occurrence is roughly but not precisely conformable with stratigraphic units. Veins or pods may be either foliated or nonfoliated and concordant or discordant with schistosity in the host rock. Sets of subparallel en echelon veins are common.

Mineralogy

Major mineral: Barite.

Minor metallic minerals: Galena, chalcopyrite, pyrite, magnetite, sphalerite, bornite(?), malachite (secondary), chalcantite (secondary).

Gangue: Sericitic white mica, quartz, chlorite, chloritoid, tourmaline (schorl), fluorophlogopite, clay (in saprolite).

Geochemical and mineral indicators

Large barium concentrations in B- or C-horizon soils (anomalous highs around old diggings may be partly

a result of past mining and soil disturbance) (Hornig, 1973); limonite pseudomorphs after pyrite in soil (Hornig, 1973); low zinc concentrations in ground-water samples (Price and Ragland, 1968); barite or abundant limonite pseudomorphs after pyrite in panned concentrates of stream sediments. Barium concentrations in nonmagnetic heavy-mineral concentrates of stream sediments are high around Kings Creek but not in other parts of the barite belt (W.R. Griffiths, oral commun., 1982). This type of geochemical exploration may be more effective for locating old mine workings than new deposits in the Piedmont, although it seems to work in arid regions (John Callahan, oral commun., 1982).

Geophysical indicators

Positive gravity anomalies in very detailed surveys may be useful in prospecting, but this approach has not been tested.

RESOURCE ASSESSMENT

The barite deposits of the Charlotte quadrangle are large and nationally significant but not currently in production. Barite was produced at Kings Creek for many years, and the outlook for future production is moderately good. Drill-hole data confirm that barite reserves at Kings Creek extend down dip (about 30°) to a vertical depth of at least 76 m (Van Horn and others, 1949). The existing mill and available rail transportation enhance the possibility of future economic production. Possible byproducts include quartz, sericite, and saprolite for bricks.

Most of the known barite deposits in the barite belt (fig. 28; Horton, 1987) appear to be smaller than those at Kings Creek, and most are in narrow, steeply dipping sets of subparallel veins that may be difficult to mine on a large scale. Other barite deposits probably are present, and a systematic exploration program could lead to their discovery.

The zone of known barite occurrence in the Battleground Formation (fig. 28; Horton, 1987) is considered to have a high resource potential. The potential for barite is low in the remainder of the Battleground Formation and virtually nil in other units of the Kings Mountain belt.

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MANGANESE OXIDES DERIVED FROM WEATHERING OF STRATABOUND SPESSARTINE-ALMANDINE GARNET IN SCHIST OF THE BATTLEGROUND FORMATION, KINGS MOUNTAIN BELT

By J. WRIGHT HORTON, JR.

GEOLOGIC SETTING

Manganese deposits occur in a single, nearly continuous stratigraphic unit of manganiferous schist within the Kings Mountain belt of the Charlotte quadrangle. Keith and Sterrett (1931) informally called this unit the manganese schist member of the Battleground Schist; Horton (1984) formally defined it as the Jumping Branch Manganiferous Member of the Battleground Formation. The Jumping Branch Manganiferous Member lies stratigraphically above a zone of high-alumina (kyanite and sillimanite) quartzites and below a zone of stratabound magnetite deposits. It is folded around the hinge of the South Fork antiform, and consequently the manganese deposits have a V-shaped distribution on the map (fig. 29). From 8 km south of Gaffney, S.C., near the southern edge of the Charlotte quadrangle, the Jumping Branch Manganiferous Member extends almost continuously northeastward for about 47 km along the western limb of the antiform to the fold hinge at Bessemer City, N.C. There it turns south and continues intermittently for another 15 km on the eastern limb of the antiform, where it occurs partly as screens within the High Shoals Granite.

The manganese occurs as lenticular veins and masses of oxides, mostly pyrolusite and psilomelane, in the weathered zone. These secondary minerals are derived from primary spessartine-almandine garnet, which is concentrated mostly in layers of coticule or gondite (garnet-quartz rock) in the manganiferous schist. The depth of oxidation is variable but is known to be at least 10 m in several places (O'Neill and Bauder, 1962).

The persistence of the Jumping Branch Manganiferous Member as a single stratigraphic unit is strong evidence for a sedimentary origin. Calcareous metasedimentary rocks adjacent to the manganiferous schist in a few places suggest a marine origin (Horton and others, 1981). The manganese and iron may have originated by chemical weathering and leaching of volcanic glass (Horton, 1977) or as distal exhalative deposits of submarine hydrothermal vents (Horton and others, 1981).

The approximately 20 prospects and small inactive mines (Keith and Sterrett, 1931; White, 1944) consist mostly of shallow pits. Only a few pits reached depths greater than 15 m. At present, several pits are intermittently worked for brown pigment used in the manufacture of bricks.

DESCRIPTIVE MODEL

Size of manganese ore bodies

Length: The manganiferous schist unit is nearly continuous for about 47 km on the west limb of the South Fork antiform and discontinuous for about 15 km on the east limb. Several continuous segments exceed 5 km in length. The largest open-pit mine is about 350 m long.

Width: The manganiferous schist unit has an average width of about 40 m and a maximum width no greater than 100 m. The dip is typically steep (greater than 80°), so the surface width closely approximates the true thickness. The largest open pit is about 40 m wide.

Depth: Map and cross-section projections indicate that most continuous segments of manganiferous schist extend to depths of 1,000 m or more. The deepest penetrations of this schist are a 26-m vertical shaft in Kings Mountain National Military Park and a 104-m cored drill hole 4.5 km south-southeast of Blacksburg, S.C. (O'Neill and Bauder, 1962). The manganiferous schist was reportedly continuous throughout the length of the drill hole. The depth of oxidation, which may limit the depth of mining, has not been determined at most places and is probably variable. It is at least 10 m deep in several pits (O'Neill and Bauder, 1962).

Volume (tonnage): The largest open pit just southwest of Kings Mountain National Military Park has produced about 70,000 m³ or roughly 300,000 short tons of weathered (oxidized) manganiferous schist for use in brick manufacture. The total amount of oxidized

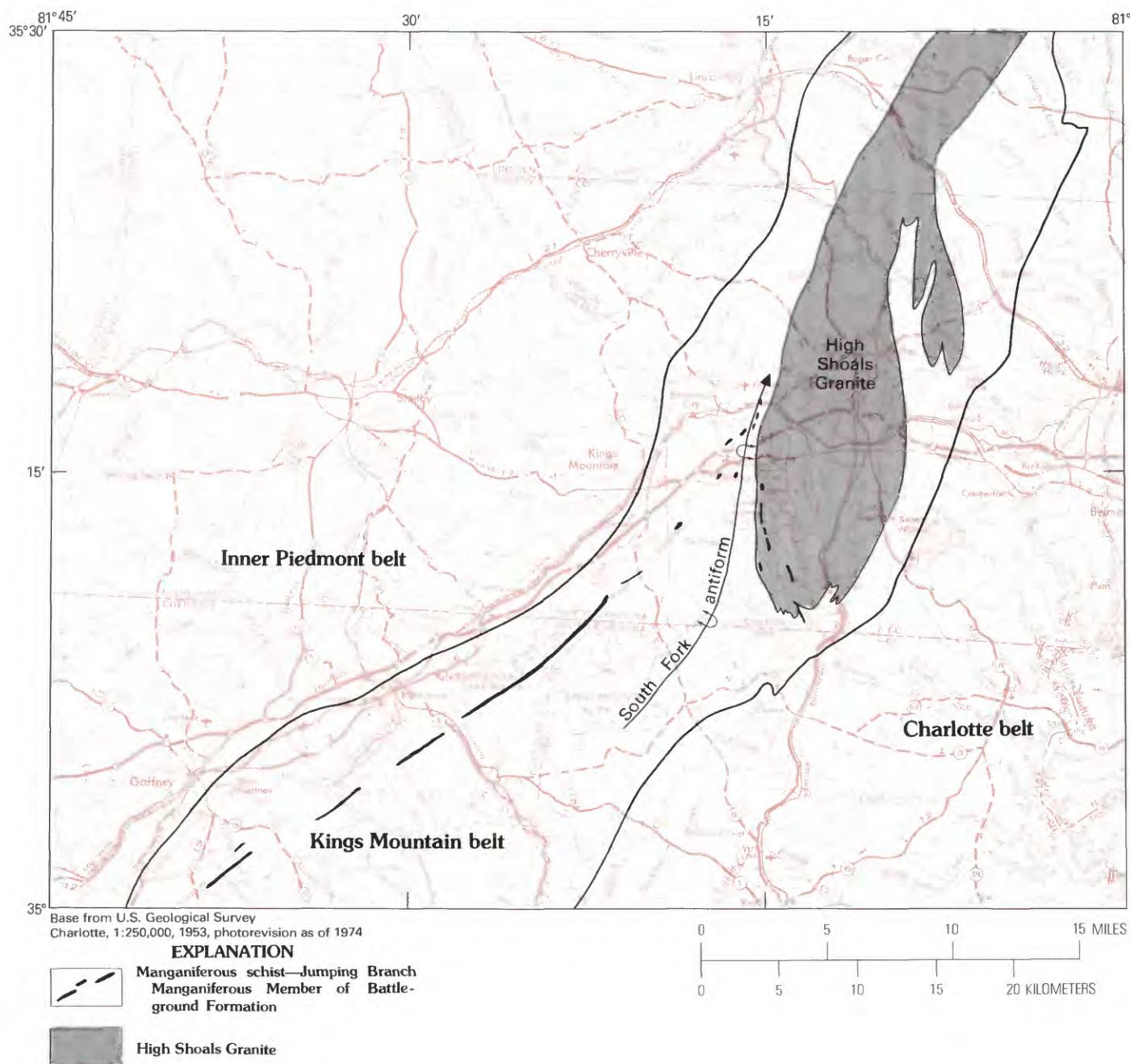


FIGURE 29.—Manganese-oxide deposits derived from weathering of stratabound spessartine-almandine garnet in manganiferous schist in the Charlotte quadrangle. The manganiferous schist (Jumping Branch Manganiferous Member of the Battleground Formation) is

folded by the South Fork antiform and, consequently, has a V-shaped distribution. On the eastern limb of the antiform, it occurs partly as screens in the High Shoals Granite.

or partly oxidized manganiferous schist in the Kings Mountain belt is unknown but probably is several million short tons to a depth of 10 m.

Grade: Five widely spaced samples of manganiferous schist collected at or near the surface reportedly average 6.4 percent manganese as oxide (O'Neill and Bauder, 1962). Chemical analyses of samples from

the 26-m shaft are relatively uniform regardless of depth and average 7.6 percent manganese and 7.2 percent iron (O'Neill and Bauder, 1962), but ratios of manganese as oxide to manganese as silicate have not been determined. Reported ratios of manganese as oxide to manganese as silicate at other prospects vary.

Lithology of host rocks

Manganiferous schist composed of fine-grained equigranular garnet (50 to 70 percent)-quartz rock (cotecule or gondite) closely interlayered with quartz-sericite schist. The spessartine-almandine garnet is concentrated in rhythmic bands generally less than 1 cm thick and also is widely disseminated. Spessartine-almandine grains are typically round and have diameters of about 0.1 mm.

Types of associations with host rocks (mode of occurrence)

In the unweathered manganiferous schist, manganese is concentrated in spessartine-almandine garnet. In the weathered zone, the manganese occurs as lenticular veins and masses of oxides, mostly pyrolusite, psilomelane, and braunite(?).

Controlling structure or relation to nearby rock bodies

The manganese occurrences are stratabound and confined to the narrow Jumping Branch Manganiferous Member of the Battleground Formation. Folding of this unit in the north-plunging South Fork antiform produces a V-shaped map pattern. Manganiferous schist on the east limb of the antiform is partly in discontinuous screens within the High Shoals Granite.

Mineralogy

Major minerals (weathered zone): Pyrolusite, psilomelane, braunite(?).

Major mineral (unweathered rock): Spessartine-almandine.

Minor metallic minerals: Hematite, magnetite (unweathered rock).

Gangue: Quartz, sericitic white mica, biotite (minor), hornblende (trace).

Geochemical and mineral indicators

Conspicuous dusky-brown manganese oxides in weathered rock, saprolite, and soil (manganese is relatively immobile under surface conditions); fine-grained spessartine-almandine garnet in panned concentrates of stream sediments; biochemical indicators as discussed by Bloss and Steiner (1960).

Geophysical indicators

Detailed magnetometer surveys (the manganiferous schist stands out on aeromagnetic maps as a line of magnetic highs, probably caused by disseminated magnetite in unweathered manganiferous schist; the manganese oxides and silicates are not magnetic); electrical surveys, particularly self potential and induced polarization, may be useful.

RESOURCE ASSESSMENT

Manganese is a strategic mineral, essential for making steel, for which the United States relies entirely on

imports, mostly from South Africa. The manganiferous schist in the Kings Mountain belt is classified as an identified mineral resource, not principally for manganese, although it has been prospected for that purpose, but for brown pigment used in brick manufacturing. Weathered (oxidized) manganiferous schist is currently mined from open pits for this purpose. The largest open pit, which is now intermittently active, has produced about 70,000 m³ of this material. Similar deposits, and larger ones, should not be difficult to locate because the stratigraphic limits are narrow and well defined. Detailed magnetometer surveys in areas where manganese oxides are conspicuous on the surface may lead to the selection of favorable areas worthy of more intensive exploration by pitting, trenching, and drilling. The depth of weathering and oxidation, an important consideration for mining, can be determined from test wells.

The Jumping Branch Manganiferous Member of the Battleground Formation appears to contain significant tonnages of potential submarginal manganese ore, although manganese production to date has been insignificant. The volume and grade of potential ore will be enhanced substantially if manganese can be recovered from the spessartine-almandine as well as the oxides. Past production of manganese is indicated by sketchy reports of a few carloads of ore shipped to mills outside the district (Keith and Sterrett, 1931).

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STRATABOUND IRON (MAGNETITE AND HEMATITE) DEPOSITS IN METASEDIMENTARY SCHIST AND QUARTZITE OF PROBABLE LATE PROTEROZOIC AGE

By JACOB E. GAIR, J. WRIGHT HORTON, JR., and JOHN P. D'AGOSTINO

GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

The earliest date for iron production in the Charlotte quadrangle was about 1786 (Nitze, 1893), near Lincolnton, Lincoln County, N.C. (fig. 30). By the early 1800's about a dozen furnaces and forges were in operation within the area of the quadrangle (Nitze, 1893).

Major centers of iron mining were at the Big Ore Bank, 1 to 2 km southeast of Pumpkin Center in Lincoln County, N.C., last mined in 1882, where workings are distributed for about 2 km along strike; at the Ormond mine, about 2 km west of Bessemer City, Gaston County, N.C., last mined in 1892, where workings extend about 730 m along strike and 30 m across strike; and at Blacksburg, Cherokee County, S.C., where 14 mines were still in operation in 1889 (Moss, 1981, p. 115).

The exploited deposits were mainly of magnetite, but some consisted primarily of brown (limonitic) iron oxide or specular hematite. Iron mines were located in the Battleground and Blacksburg Formations of the Kings Mountain belt, generally on steeply dipping stratabound lenses of the iron oxides. Ferruginous lenses trend N. 10° E. to N. 30° E. in a few narrow zones in Gaston, Lincoln, and Catawba Counties, N.C., and across part of Cherokee County, S.C., in the "old iron district" a few kilometers east of Gaffney. Trends are variable in the hinge area of the Cherokee Falls synform in Cherokee County (fig. 30; D'Agostino and Rowe, 1986). These iron-rich zones extend across south-central Gaston County, passing 1 to 4 km east of the town of Kings Mountain. The iron-rich belt crosses Lincoln County and the southeast part of Catawba County, passing 1 to 6 km east of Lincolnton and along the east base of Anderson Mountain (Nitze, 1893). The grade of the deposits was high, commonly 65 percent iron for magnetite deposits and 58 percent iron for hematite deposits, but total production was small and probably did not exceed 1 million tons. Production had largely ceased by the end of the Civil War, except from a few of the larger deposits of the area, where mining continued until the 1880's and 1890's.

Ferruginous lenses are chiefly enclosed conformably within layers of quartzose sericite schist. The long, narrow ferruginous zones commonly consist of two or three parallel iron-rich lenses separated by layers of schist as much as several meters in thickness. In the belt east of Kings Mountain, there are three major parallel iron-rich layers, two of brown hematite and limonite on the west, about 1.2 km from one another, and one of magnetite, 2.5 km farther east. Manganiferous rock occurs near some of the ferruginous rock in the Kings Mountain belt and is discussed separately in the previous section on stratabound manganese deposits by Horton. Ferruginous lenses range in thickness from about 15 cm to 8.5 m but average about 2 to 2.5 m, and individually most are a few hundred meters or less in length. The zones containing these ferruginous lenses are as much as 15 km in length and are not wider than a few hundred meters except where they are repeated by folding.

Polished sections reveal three modes of magnetite-hematite occurrence: (1) granular magnetite with quartz, (2) pseudomorphs of the iron minerals that replaced tabular gangue minerals of unknown original composition, and (3) inclusions or exsolution blebs of the iron minerals in euhedral pyrite crystals (Posey, 1981, p. 135). Hematite rims are common on magnetite grains. The magnetite replacing tabular gangue minerals outlines folds and kinks, although there is no other evidence of deformation of the rock fabric. The magnetite may have been introduced or remobilized during the later stages of metamorphism (Posey, 1981, p. 135).

DESCRIPTIVE MODEL

Size of ferruginous lenses and zones

Length: Lenses mined were about 30 to 780 m long; zones of ferruginous lenses, as much as 15 km in length.

Width: 15 cm to 1 m for hematitic lenses and 15 cm to 5.5 m for magnetite lenses, averaging 2 to 2.5 m. Big Ore Bank near Lincolnton consisted of three parallel

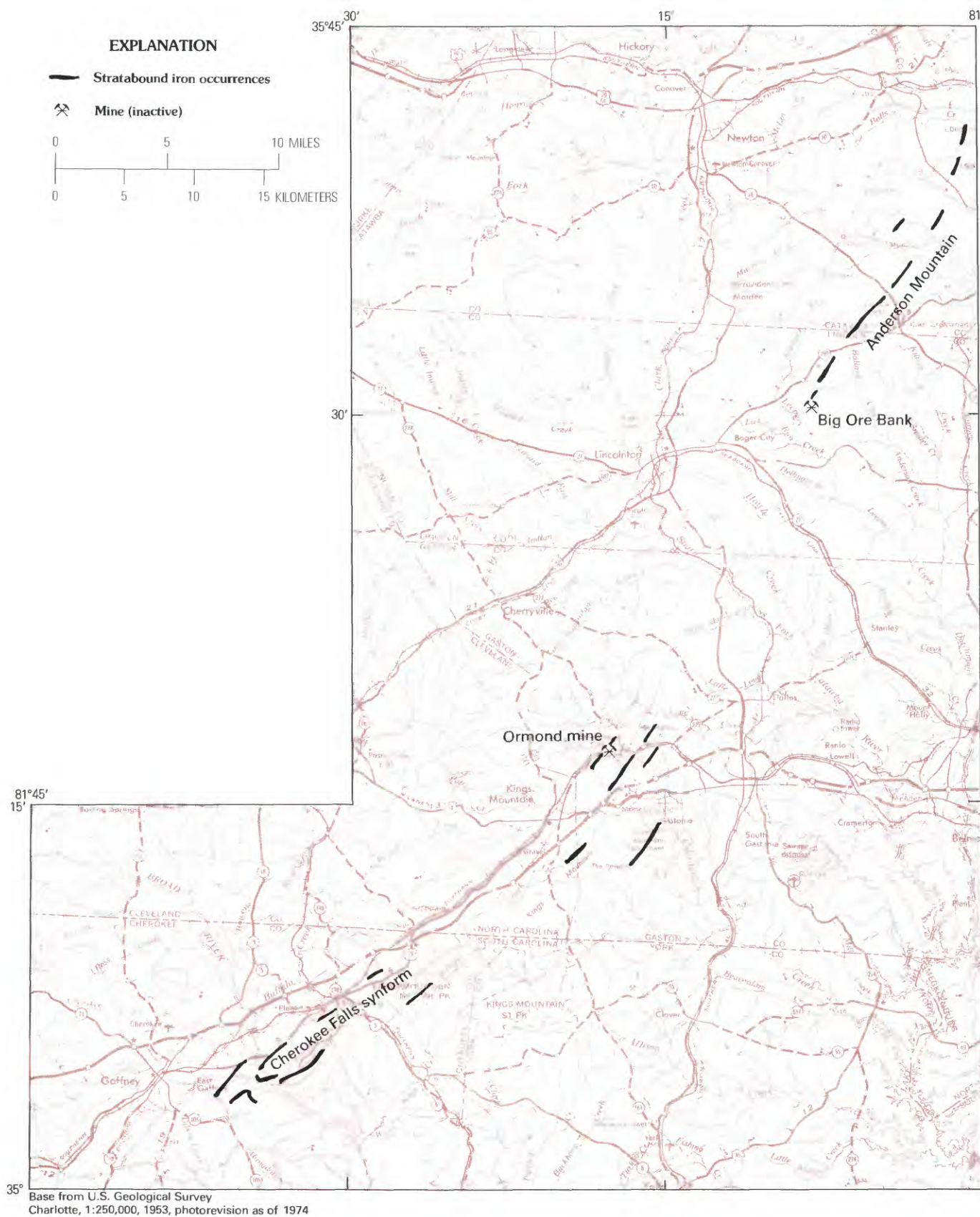


FIGURE 30.—Distribution of stratabound iron occurrences in the Charlotte quadrangle.

magnetite lenses, 2.5, 3.6, and 5.5 m thick, separated by layers of schist, 1 to 1.3 m thick. Aggregate thickness of parallel ferruginous layers in a few places as much as 30 m.

Depth: Most deposits mined to less than 30 m. Deepest shaft, at Ormond mine near Bessemer City, 24 km west of Gastonia, N.C., was about 53 m deep. Ferruginous lenses probably extend below surface about same distance or less than their respective strike lengths, but discontinuous lenses of about the same dimensions as those at the surface probably occur along projections of ferruginous horizons to depths of a thousand meters or more.

Volume (tonnage): The largest lens mined (at Ormond mine) may have contained 0.5 million tons of iron ore to a depth of 100 m, although apparently considerably less than this amount was mined. The smallest lenses mined contained 2 to 4 tons; mined lenses of average dimensions probably each contained 60,000 to 80,000 tons, and remaining material at the Big Ore Bank deposit is probably 300,000 tons.

Grade: Grade of iron ore mined ranged from 45 to 65 percent iron; average grade estimated in range 55 to 60 percent iron. Grade at the Big Ore Bank deposit is 28.4 percent iron.

Lithology of host rocks

Quartz-sericite schist, locally chloritic, in the Battleground and Blacksburg Formations of the Kings Mountain belt. Wallrock schists may contain quartz stringers and pods or lenses of fine-grained quartz. Marble lies west of the ferruginous zones of the Kings Mountain belt.

Types of associations with host rocks (mode of occurrence)

Lenses and pods conformable with schistosity of host rocks and conformable in trend and overall extent with the Kings Mountain belt, with some gaps in occurrence of iron-rich lenses along the trend of the ferruginous zones. Schistosity typically dips steeply or vertically. Some sets of parallel ferruginous lenses may have been deposited successively; others are a single layer repeated by folding.

Controlling structure or relation to nearby rock bodies

Conformable with nearby stratigraphic units. Folded around hinge of Cherokee Falls synform in Cherokee County, S.C.

Mineralogy

Major metallic minerals: Magnetite, specular hematite, limonite.

Minor metallic minerals: Pyrite, chalcopyrite.

Gangue: Quartz, sericite, white mica, chlorite (locally), manganese oxides, feldspar, hornblende, apatite(?).

Geochemical and mineral indicators

Unusually ferruginous soil with surface accumulations of residual iron-oxide gravel. Magnetite or specular hematite in stream sediments.

Geophysical indicators

Linearly aligned magnetic anomalies within and parallel to rock units of the Kings Mountain belt.

RESOURCE ASSESSMENT

The zones of ferruginous rock (fig. 30) have nil to low potential for iron resources. The aggregate volume of ferruginous rock is large, but high-grade material containing 60 to 65 percent iron comparable to the richest ore previously mined in the area probably occurs only very locally. Most such occurrences near the surface probably have been found, but it is likely that others occur at depths of 50 to 100 m or more below the surface.

During World War II, interest in the Big Ore Bank deposit was revived when it was rated as potentially economic in a study by H.A. Brassert and Company (Eaton, 1943). In 1943 and 1944, following a detailed magnetic survey by the North Carolina Geological Survey, the U.S. Bureau of Mines drilled 10 exploratory holes, aggregating a total of 4,493 linear feet of core (Clayton and Montgomery, 1948). On the basis of this drilling, ore reserves at the Big Ore Bank deposit were estimated to be 300,000 short tons, averaging 28.4 percent iron, which could yield 100,000 tons of concentrate (Murdock, 1950, p. 11).

Despite the probability that small bodies relatively rich in iron occur within the zones of ferruginous rocks in the area, the potential for iron resources must be considered low at best because iron deposits of comparable or better grades, and orders of magnitude larger, are being mined at many places elsewhere in the world and will be able to satisfy world needs for hundreds of years. It is unlikely that detailed magnetic surveys and other exploratory methods necessary to find subsurface iron concentrations will be undertaken in the Charlotte area in the foreseeable future.

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IRON (MAGNETITE) DEPOSITS ASSOCIATED WITH FELSIC AND MAFIC GNEISSES

By DANIEL J. MILTON, JOHN P. D'AGOSTINO, and JACOB E. GAIR

GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

A small iron production, estimated to be less than 100,000 tons, was derived from magnetite ore of probable contact or metasomatic origin in the Inner Piedmont of Catawba and Lincoln Counties (D'Agostino and Rowe, 1986). Magnetite was said to be concentrated at a contact between felsic (granitoid) gneiss and hornblende gneiss at the Barringer and Forney mines (fig. 31; Nitze, 1893). Other deposits occur farther south in Lincoln County to the east and west of Lincolnton. The Barringer and Forney mines ceased operations long before Nitze's report (1893), and virtually nothing is known of their history. All the deposits occur in areas of complex but very poorly exposed granitoid and mafic gneisses and evidently occur as small pockets and pods of high-grade magnetite ore distributed along contacts between the different gneisses. A feldspar-free quartz-garnet (andradite to grossular)-epidote-hornblende-hedenbergite-sphene gneiss containing minor magnetite, ilmenite, and pyrite occurs near the site of the Barringer mine, and a scapolitic ultramafic rock is near the site of the Forney mine. The former rock may be a skarn. At the Forney mine, old pits are spread over a distance of about 2 km. The iron content of the ore at these locations was as high as 69.8 percent.

DESCRIPTIVE MODEL

Size and grade of ferruginous deposits

Length: Unknown; at Forney mine, probable lenses and pods of magnetite extended for about 2 km along strike.

Width: A few centimeters to about 1.3 m (at Forney mine).

Depth: Unknown; individual bodies probably shallow. Workings at least 8 m deep at Forney mine.

Volume (tonnage): Total volume of an unknown number of individual bodies mined probably was less than 100,000 tons.

Grade: 65 to 69.8 percent.

Lithology of host rocks

Felsic (granitoid) and mafic (hornblende) gneiss; probable skarn; ultramafic rock.

Controlling structure or relation to nearby rock bodies

Associations and structure in the environs of the deposits are poorly known, but many magnetite pods or lenses occur at contacts between different gneiss units. Relation to these rocks unknown.

Mineralogy

Metallic minerals: Magnetite; minor ilmenite(?).

Gangue: Little or none; traces of quartz, feldspar, and hornblende.

Geochemical and mineral indicators

Local concentrations of magnetite in soil and stream sediment.

Geophysical indicators

Aeromagnetic highs in general vicinity of deposits suggest magnetite concentrations; local magnetic anomalies, detectable and traceable by ground magnetic surveys.

RESOURCE ASSESSMENT

Areas of granitoid and mafic gneisses near the known deposits, especially on strike with them and at depth, have a moderate to low potential for the occurrence of additional small deposits. Areas of moderate potential located within a few kilometers of known deposits can be upgraded to areas of high potential by identifying magnetic anomalies through use of ground magnetic surveys. The probable small size of such deposits and the likelihood that most undiscovered deposits would occur at some depth below the land surface, requiring deep pits (relative to deposit size) or underground mining, preclude any likelihood of development, even if deposits were found. The resource potential of such deposits is nil.

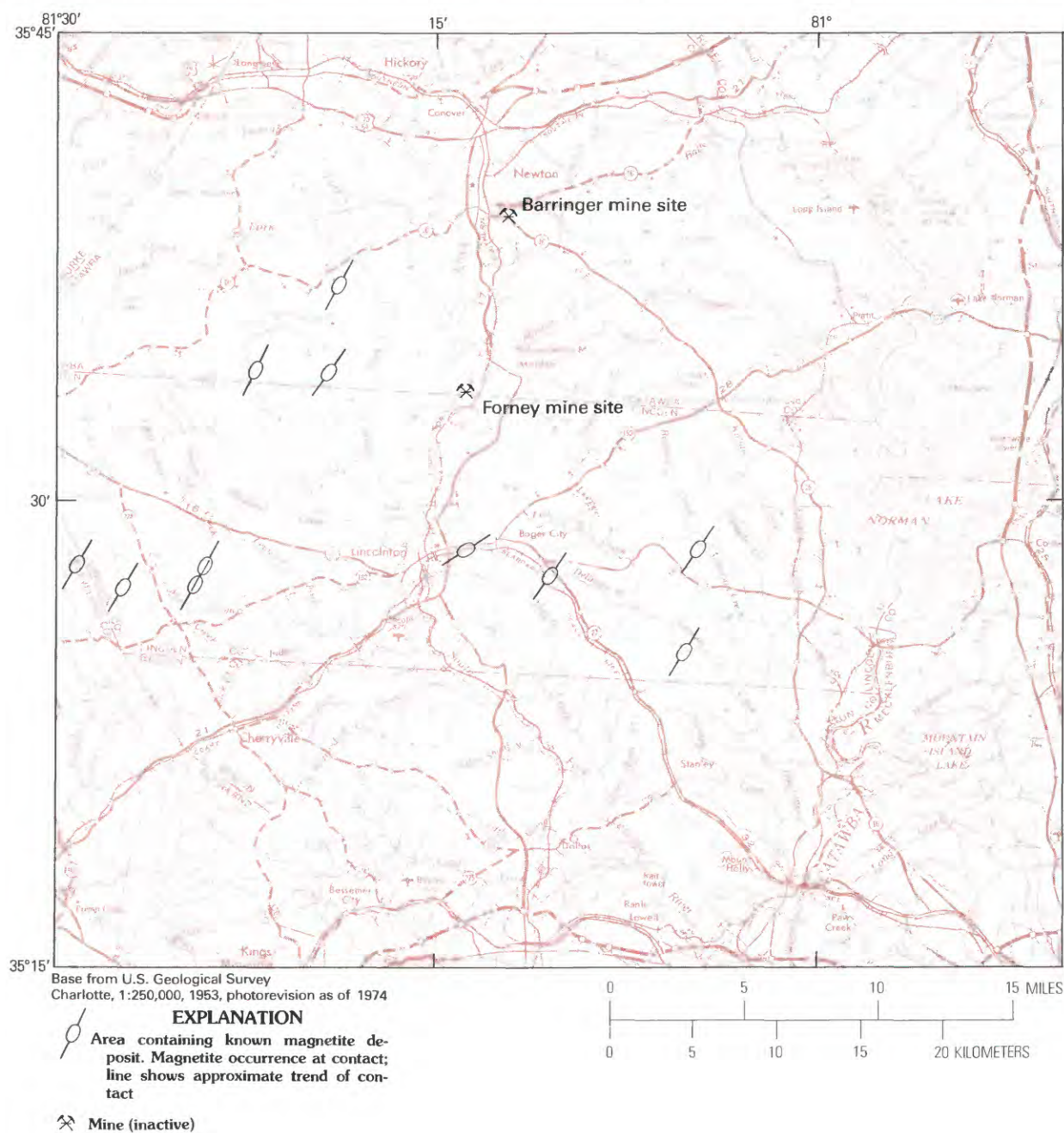


FIGURE 31.—Areas of magnetite deposits at contacts between felsic (granitoid) gneiss and hornblende gneiss in the Charlotte quadrangle.

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CORUNDUM DEPOSITS ASSOCIATED WITH AMPHIBOLE-RICH ROCKS

By JACOB E. GAIR, DANIEL J. MILTON, JOHN P. D'AGOSTINO, and JESSE W. WHITLOW

GEOLOGIC SETTING AND HISTORY OF DEVELOPMENT

Corundum deposits have been found at a few places in the Charlotte quadrangle associated with amphibole-rich rocks. Such deposits are within the amphibole-rich rock, in feldspar-vermiculite veins within amphibole-rich rock, or in granitoid gneissic rocks near contacts with amphibole-rich rock. Corundum also occurs in sillimanite schist and gneiss as shown by its presence in pan concentrates (table 5, no. 2). Corundum, however, is not known to be sufficiently concentrated in these rocks, or in placers resulting from their erosion, to constitute potential resources.

Only two mines in the Charlotte quadrangle are known to have produced corundum (fig. 32). The Acme mine located about 1.2 km west of Statesville in Iredell County, N.C., produced 50 tons of corundum concentrate in the 1890's, and the Rickard mine in York County, S.C., west of the road junction called Five Points about 11 km east of Clover, produced an unspecified amount of corundum in the late 1890's. All or most of the production from the Acme mine was from alluvial gravels, but the apparent source was a vein of feldspar, vermiculite, and corundum 0.75 m thick in amphibole-rich rock beneath the alluvium. The amphibole-rich rock probably is enclosed by granitoid gneiss of the Inner Piedmont belt and is either a dike or a conformable layer. The Acme occurrence is similar to another occurrence 11 km west of Statesville and is probably analogous to widespread ultramafic corundum-bearing rock bodies enclosed in granitoid gneisses within the Blue Ridge belt west of the Charlotte quadrangle. A local prospector reported an occurrence of corundum about 10 km northwest of Statesville. Corundum at the Rickard mine (Charlotte belt) was recovered both from surface float and by underground mining. There, corundum occurs in quartz diorite near contacts of actinolite-chlorite-serpentine amphibolite enclosed by the quartz diorite. Other corundum occurrences known in the Inner Piedmont and Charlotte belts are disseminations in felsic gneisses and quartzose schists, but the small amount of corundum in these occurrences does not warrant consideration of them as mineral deposits. The corundum at the

known occurrences is found in rounded masses several centimeters in diameter and as small grayish, brown, or black crystals or clusters of crystals. The corundum may be associated with muscovite, margarite mica, fibrolitic sillimanite, vermiculite, tourmaline, actinolite, hornblende, or kyanite. Individual aggregates may contain 50 to 100 kg of corundum.

DESCRIPTIVE MODEL

Not enough is known about this type of deposit to complete the detailed outline being used for the descrip-

TABLE 5.—Occurrences of corundum in pan concentrates, Charlotte quadrangle

No. on figure 32	Location and distribution
1	Area extending about 10 km northeast and east from Shelby, N.C. Samples from Buffalo Creek and its tributaries, particularly Potts Creek and Whiteoak Creek.
2	Area extending 5 km east and about 11 km south and southeast from Kings Mountain, N.C. Samples from streams draining west, north, southeast, and south from the Kings Mountain ridge and The Pinnacle.
3	Area around and within 2 km of Nanny Mountain, S.C. Samples from streams draining east to southeast and west to southwest from Nanny Mountain. These occurrences are about 2 km south of the Rickard deposit.
4	Area south of the city of Charlotte, between Pineville and Weddington, N.C. Samples from tributaries of Sixmile and McAlpine Creeks.
5	Single sample, Back Creek, northeast of the city of Charlotte, about 3 km northeast of village of Newell, N.C.
6	Single sample, 2 km east of Mocksville, Davie County, N.C.
7	Single sample, Powder Mill Branch, tributary of Hicks Creek, 10 km south of Statesville, N.C.
8	Single sample, south of Lake Norman, about 2 km northeast of Lowesville, N.C.
9	Single sample, from tributary, south side of Long Creek, about 5 km northwest of center of Gastonia, N.C.
10	Single sample in southwest corner of Lincoln County, N.C., north of State Rd. 182 and about 4 km east of Fallston.
11	Single sample, northern Cleveland County, N.C., about 2 km south of boundary with Burke County, 4 km west of village of Olive Grove.

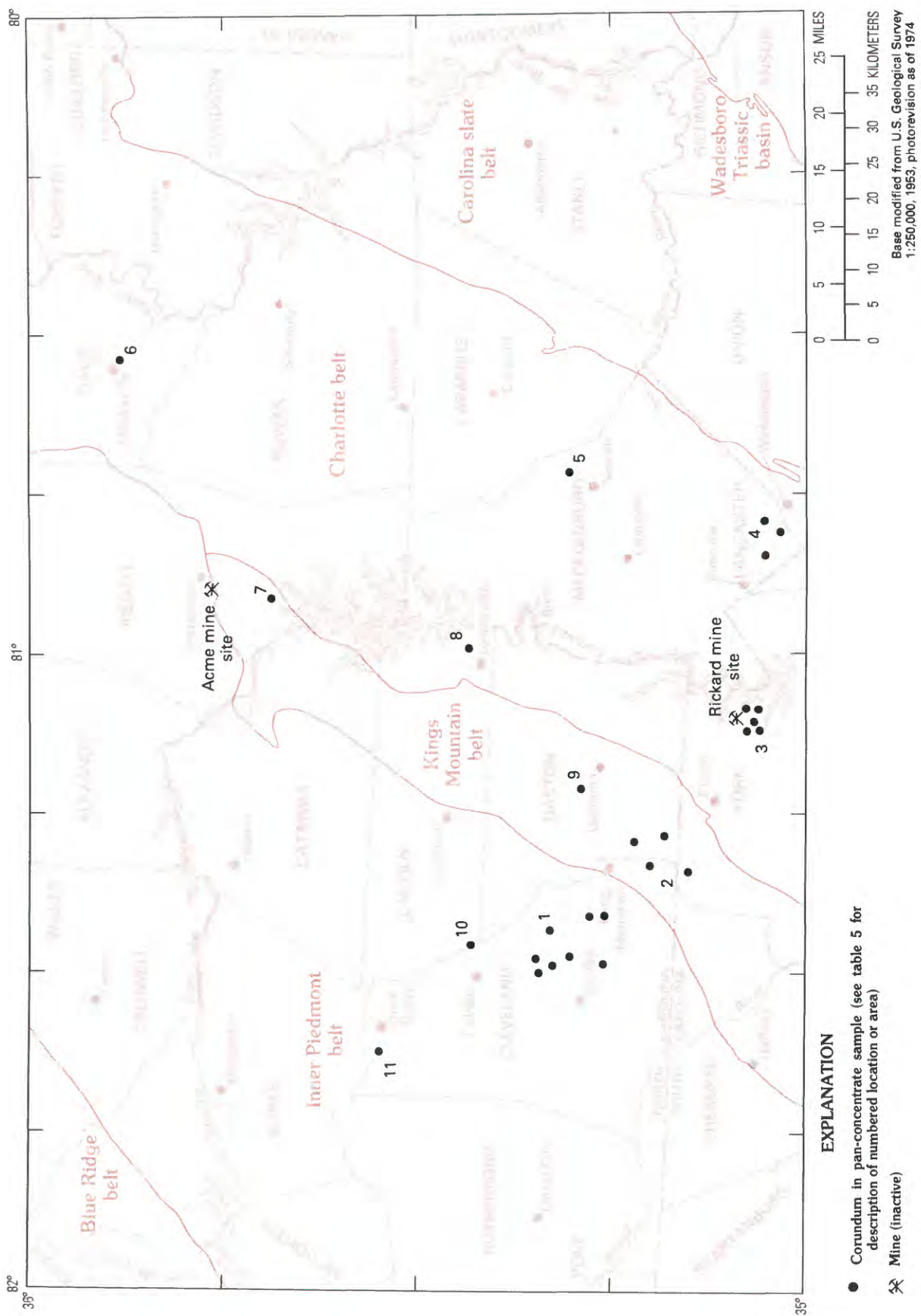


FIGURE 32.—Occurrence of corundum in the Charlotte quadrangle.

tive models of most deposit types of the Charlotte area. Corundum-bearing veins or zones apparently are rarely more than 1 m thick, and their trends, extent, and grades are generally unknown. At the Rickard mine, a vein 2 ft (0.6 m) thick reportedly had a grade of 5.7 percent corundum. The veins at the Rickard and Acme mines, near contacts between amphibole-rich or other mafic host rocks, apparently are a product of metamorphic reactions between the mafic and granitoid rocks. There are many such contacts between mafic and granitoid rocks in the Charlotte quadrangle, but most of them bound small bodies disregarded at the scale of the mapping and, therefore, are not shown on the geologic map of the quadrangle (Goldsmith and others, 1988). Conditions favorable for corundum accordingly occur in many places but cannot be targeted for prospecting from the available map. Prospecting should focus on examining alluvial gravels that overlie or are short distances downstream from areas of amphibole-rich rock surrounded by areas of granitoid biotite gneiss or felsic plutonic rocks of the Inner Piedmont and Charlotte belts.

RESOURCE ASSESSMENT

A number of corundum occurrences have been found in pan concentrates in the Charlotte quadrangle (table 5;

fig. 32). Stream valleys upstream from these occurrences (nos. 1–4 in table 5 and fig. 32), and a north-south belt passing just west of Statesville, N.C., and extending about 10 km to the north and 10 km to the south are the places in the quadrangle having the best potential for corundum resources. In the absence of other information, areas of the Charlotte belt and Inner Piedmont gneisses upstream from sites of corundum-bearing pan concentrates are considered to have low potential for corundum resources.

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URANIUM IN PEGMATITIC VEINS, FRACTURE FILLINGS, AND SHEARS IN GRANITES AND GNEISS

By JACOB E. GAIR and RICHARD GOLDSMITH

DISTRIBUTION AND RESOURCE POTENTIAL

Almost all concentrations of uranium reported from the Charlotte quadrangle are in the Blue Ridge in the northwestern corner of the quadrangle. Most are in the Chestnut Mountain 7.5-minute quadrangle (fig. 33; Grauch and Zarinski, 1976, table 1, nos. 6, 11–16, 18–19; Crandall and others, 1982; Gair, 1986) and the adjacent Grandfather Mountain 7.5-minute quadrangle, which is north of the Charlotte quadrangle in the Winston-Salem 1°×2° quadrangle (Reed, 1964; McHone, 1982). The principal host rock is the 1-b.y.-old Wilson Creek Gneiss. No production has been reported from these localities, and no additional study of them has been done as part of CUSMAP. Fine-grained alluvium and well waters of the area were sampled for uranium during the National Uranium Resource Evaluation (NURE) program (Heffner and Ferguson, 1978).

The uranium occurs in uraninite-bearing pegmatitic veins, principally those that fill fractures, in uraninite veins as much as 1 cm thick in fractures and shear zones in gneiss, and in torbernite coatings on shear and slickensided surfaces. In addition, altered areas in schist and gneiss contain radioactive zones in which no radioactive mineral has been identified. Radioactivity reported by Grauch and Zarinski (1976) from these localities ranges from 5 to 40 times or more background radiation. At one place, a radioactivity of 17 mR/hr is estimated to be several hundred times greater than background. Most of the radioactivity can be directly related to the uraninite-bearing veins or to the smears of torbernite, but at many places no radioactive mineral is visible.

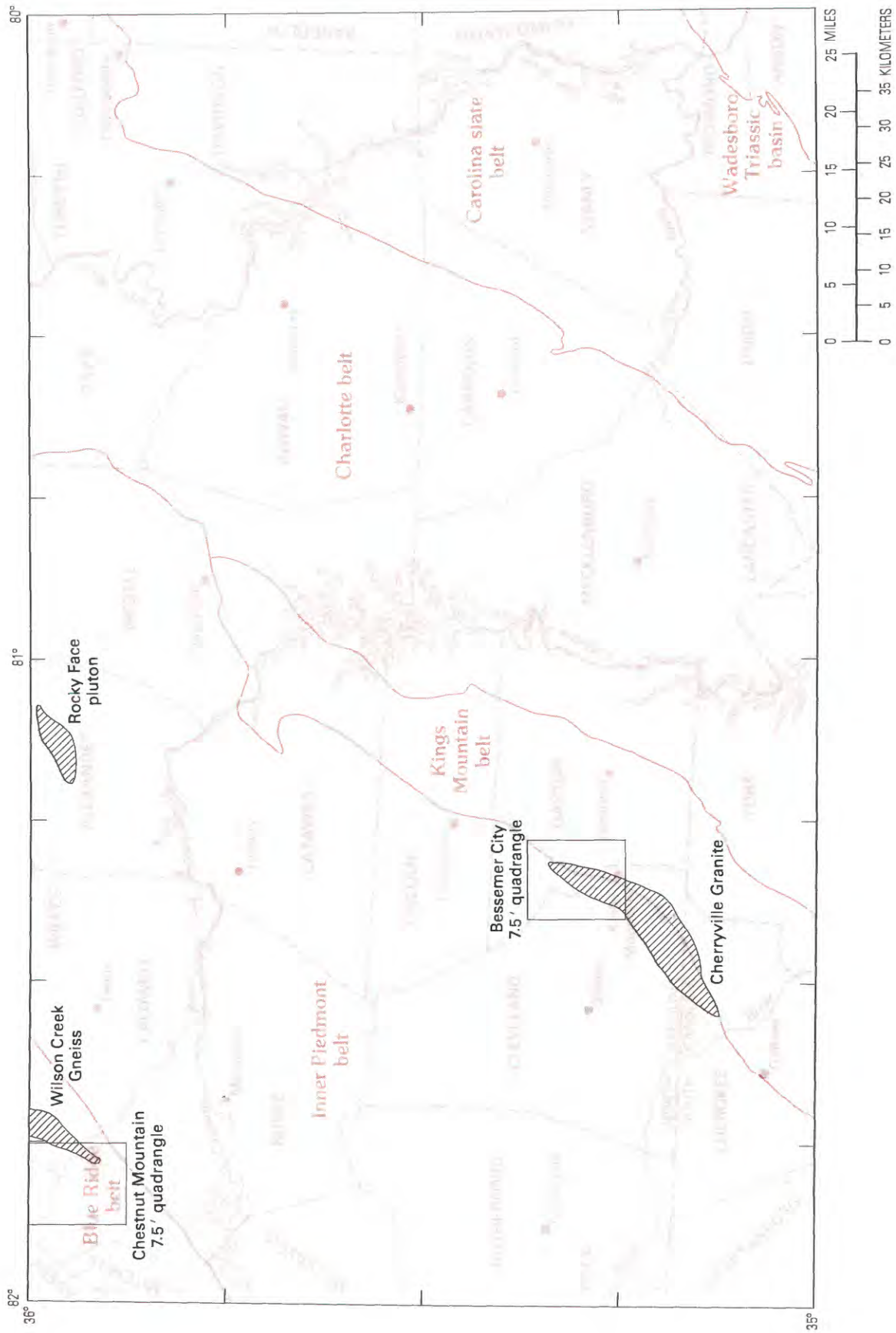
Anomalous uranium has been reported from two other places in the Charlotte quadrangle (fig. 33). Grauch and Zarinski (1976, table 11, no. 1) report a high uranium content in the Toluca Granite at a quarry in the Rocky

Face pluton in Alexander County and in the Cherryville Granite in the Bessemer City 7.5-minute quadrangle (see also their table 11, no 21).

The amounts of uranium at all of the localities in the quadrangle are small and do not constitute a significant resource potential. The presence of numerous small veins and shear surfaces containing uranium minerals in the Wilson Creek Gneiss, however, suggests that this entire rock unit is an area of low resource potential for uranium.

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Base modified from U.S. Geological Survey
1:250,000, 1953, photorevision as of 1974

FIGURE 33. — Major areas of uranium occurrence (indicated by striping) in the Charlotte quadrangle.

CONSTRUCTION MATERIALS

By JACOB E. GAIR, RICHARD GOLDSMITH, JOHN P. D'AGOSTINO, DANIEL J. MILTON, and PATRICIA J. LOFERSKI

GEOLOGIC SETTINGS

Construction material (crushed stone, sand and gravel, clay for brick, dimension stone, and flagstone) has been a major commodity in the Charlotte quadrangle (see DeYoung and Lee, this volume). The value of all construction materials produced in the area through 1978 is more than \$800 million (1967 dollars), about three times the value of all other mineral commodities combined. Crushed stone, dimension stone, and flagstone are derived from a variety of bedrock sources. Areas of potential resources are essentially coextensive with the boundaries of favorable formations; within such boundaries more highly favorable areas are governed by local conditions, particularly the depth and nature of the weathering profile. Sources favorable for crushed stone are so widespread in the area (fig. 34) that a major factor controlling development in most places is local need. Sand and gravel and clays are formed by reworking or weathering a variety of geologic materials or "deposit types." Therefore, most of the construction materials are not related to a single deposit-type model. Most clay is derived from saprolite and is mined for the manufacture of bricks, but a less common, high-quality clay is used for ceramics; the residual clays are discussed in the section "Saprolite deposits." Clay for bricks is also obtained from fine-grained alluvium in stream bottoms and by direct quarrying of mudstone units in the Carolina slate belt.

No systematic methodology has been used in this study to identify areas of potential resources of construction materials. Areas of present and past production are shown by D'Agostino and Rowe (1986), and areas of active production in 1976 are shown on a map accompanying a report by McDaniel and McKenzie (1976). Areas of potential resources of various construction materials are shown by Goldsmith, Horton, and others (1986). The factors discussed here and the history of different rock units as sources of crushed stone are the bases for assigning degrees of resource potential for crushed stone to the mapped formations. The distribution of the areas of crushed stone potential therefore corresponds to mapped units and can be adequately presented only on a full-scale (1:250,000) map (see Goldsmith, Milton, and

Horton, 1988); this report only highlights the major rock units favorable for crushed stone.

A key empirical factor in identifying favorable units is a history of production. Rock units that have been major sources of crushed stone are identified (table 6) by the fact that they contain important quarries. In general, areas of greatest potential for all the construction materials are adjacent to the known production localities, and areas of less potential are extended from these localities in the same type of rock or within the boundaries of a physiographic feature with which sand and gravel or clay may be associated.

The following subsections cover the principal occurrences of construction materials, the geologic formation or setting of each material, and the potential for additional resources of each material. Similar information for residual clay is presented in the section "Saprolite deposits."

CRUSHED STONE (INCLUDING BROKEN STONE AND WEATHERED FRAGMENTAL MATERIALS)

Crushed stone is probably the most widely available and commonly used mineral material in the quadrangle. Crushed stone is used principally for concrete aggregate, roadbeds, and road surfacing. The value of all reported stone production through 1978 is about \$625 million (1967 dollars), a large part of which was for crushed stone (see DeYoung and Lee, this volume). Granitic plutonic rocks, including the Henderson Gneiss, and layered biotite gneiss of the Inner Piedmont and Charlotte belts are probably the most important sources of crushed stone; other rocks in common use are amphibolite, as a byproduct of spodumene mining, and intrusive metagabbro and metadiorite of the Inner Piedmont, Kings Mountain, and Charlotte belts. Crushed mudstone from units of the Carolina slate belt has been an important material in the manufacture of bricks. Mapped units that have provided major amounts of crushed stone are the Toluca Granite, Henderson Gneiss, granites of the Churchland Plutonic Suite in the Gastonia pluton, Clover pluton, York pluton, and others northward to the Churchland pluton (fig. 34), and biotite gneiss of the Inner Piedmont belt (Goldsmith,

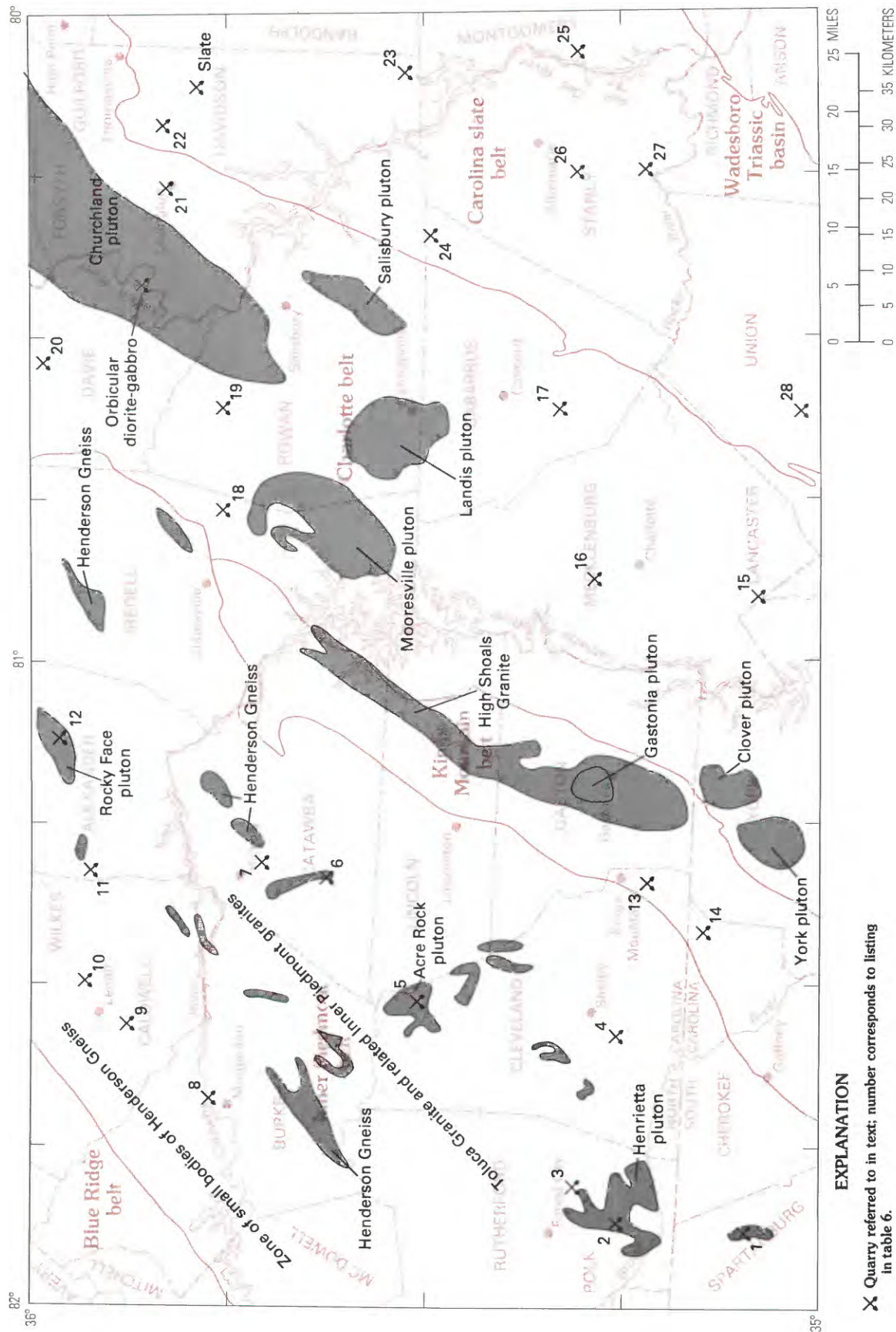


FIGURE 34. — Areas most favorable for resources of crushed stone and dimension stone in the Charlotte quadrangle.

TABLE 6.—*Representative quarries from which crushed stone is or has been produced in the Charlotte quadrangle and types of rock quarried*

Map no. (fig. 34)	Quarry location	Quadrangle	Rock type
Inner Piedmont belt			
1	0.5 km east of Buck Creek, 5 km southwest of Chesne, Spartanburg County, S.C.	Cowpens 7.5-minute	Porphyritic gneissic granite of Sandy Mush.
2	1.7 km southwest of Sandy Mush on tributary of Floyd Creek, Rutherford County, N.C.	Forest City 7.5-minute	Porphyritic gneissic granite.
3	3.4 km southwest of Ellenboro, N.C., on slope southwest of Oak Grove Church, Rutherford County, N.C.	Forest City 7.5-minute	Layered biotite gneiss.
4	Hickory Creek near Cleveland Country Club, just outside Shelby, Cleveland County, N.C.	Shelby 15-minute	Biotite gneiss.
5	1.2 km southwest of Toluca, Acre Rock, Cleveland County, N.C.	Casar 7.5-minute	Toluca Granite.
6	Jacob Fork, 1 km west of junction with Henry Fork, Catawba County, N.C.	Hickory 7.5-minute	Granitoid biotite gneiss.
7	Martin Marietta quarry, Clark Creek, 1.5 km south of Sweetwater and 3.2 km southeast of Hickory Center, Catawba County, N.C.	Hickory 7.5-minute	Garnetiferous Henderson Gneiss.
8	2.2 km northeast of Morganton and east of Hunting Creek, Burke County, N.C.	Lenoir 7.5-minute	Migmatitic biotite gneiss.
9	Causby quarry, 4.2 km south of Lenoir City Hall, Caldwell County, N.C.	Lenoir 7.5-minute	Layered migmatitic gneiss.
10	Miller Brothers quarry, 1.5 km northeast of Hibriten High School, Lenoir, Caldwell County, N.C.	Lenoir 7.5-minute	Migmatitic granite gneiss.
11	0.6 km north of N.C. Route 90 on County Road 1300, northwest of Oxford Memorial Church, Alexander County, N.C.	Ellendale 7.5-minute	Layered biotite gneiss.
12	Southwest flank of Rocky Face Mountain on County Road 1426, 2.3 km northwest of Rocky Springs, Alexander County, N.C.	Taylorsville 7.5-minute	Gneissic biotite granite.
Kings Mountain belt			
13	Martin Marietta (formerly Superior Stone) Kings Mountain crushed rock quarry, 1.2 km south of Kings Mountain, Cleveland County, N.C.	Kings Mountain 7.5-minute	Marble.
14	Vulcan Materials Grover quarry, 2 km southeast of Grover, N.C., in Cherokee County, S.C.	Grover 7.5-minute	Marble.
Charlotte belt			
15	Pinewood quarry, 0.8 km north of Pineville, Mecklenburg County, N.C.	Fort Mill 7.5-minute	Metagabbro.
16	Charlotte quarry, 9 km north of downtown Charlotte, Mecklenburg County, N.C., and northeast of Capps Hill	Derita 7.5-minute	Amphibolite.
17	Syenite quarry, 7 km northwest of Flows Store, Cabarrus County, N.C.	Concord SE 7.5-minute	Massive to slightly foliated syenite.
18	Elmwood quarry, 1.5 km northeast of Elmwood, Iredell County, N.C.	Statesville East 7.5-minute	Metagabbro.
19	Woodleaf quarry, 1.5 km northeast of Woodleaf, Rowan County, N.C.	Cooleemee 7.5-minute	Leucocratic granite.
20	Smith Grove quarry, 2 km west of Smith Grove, Davie County, N.C.	Mocksville 7.5-minute	Gabbro.
21	Lexington quarry, 1.2 km north of center of Lexington, Davidson County, N.C.	Lexington West 7.5-minute	Quartz diorite.
22	Mayers quarry, 3.8 km north-northeast of Holly Grove, Davidson County, N.C.	Lexington East 7.5-minute	Metavolcanic rock
Carolina slate belt			
23	Jacobs Creek Flagstone Co. Nor-Carla Bluestone quarry, 4.5 km northwest of southeast corner of Davidson County, N.C.	Handy 7.5-minute	Meta-argillite.
24	Gold Hill quarry, 2.2 km south-southeast of Gold Hill, Cabarrus County, N.C.	Gold Hill 7.5-minute	Metasiltstone.
25	5 km north and slightly west of PeeDee, Montgomery County, N.C.	Morrow Mountain 7.5-minute	Felsitic lithic crystal tuff.
26	McManus quarry, 6 km southwest of Albemarle, Stanly County, N.C.	Albemarle 7.5-minute	Metasiltstone.
27	Solite Corporation Aquadale expandable light aggregate and crushed stone quarry, 1.5 km west of Aquadale, Stanly County, N.C.	Aquadale 7.5-minute	Metasiltstone.
28	Bakers quarry, 0.5 km north-northwest of Bakers, Union County, N.C.	Bakers 7.5-minute	Metasiltstone

Milton, and Horton, 1988). Metasiltstone in the Carolina slate belt near Aquadale, Stanly County, N.C., is quarried both for crushed stone and for material to be expanded by heat to form lightweight aggregate. The rock contains dispersed pyrrhotite (several percent), which seems to be responsible for the favorable expanding characteristics.

A list, by no means exhaustive, of existing and abandoned quarry sites and representative types of rock used as sources of crushed stone is given in table 6, and locations are shown in figure 34.

DIMENSION STONE

Dimension stone constitutes a few percent of the value of all stone quarried in the Charlotte quadrangle. The value of dimension stone per unit of weight is 25 times that of crushed stone. Most dimension stone is granite from the Salisbury pluton south and southeast of Salisbury, N.C., and, to a lesser extent, from the Clover pluton in York County, S.C. (fig. 34). The Salisbury pluton, an elongate northeast-trending body 18 km long and 3 km wide, has been quarried at 47 sites from before the Civil War to 1980; the Clover pluton was quarried until 1908.

Dimension stone has been used for millstones, monuments (principally headstones), foundations, curb and paving stones, and windowsill and doorsill stones. The rocks consist mainly of feldspar and quartz, some biotite, and a number of other minerals. They are suitable for dimension stone because they can be readily split into sizable blocks and take a high polish. The granite of the Salisbury pluton varies in color, making it difficult to market sufficient quantities of a uniform product. This heterogeneity lowers the resource potential of the remaining unexamined parts of the pluton.

Two unusual varieties of dimension stone have been quarried in the past in the Charlotte quadrangle: (1) an orbicular diorite-gabbro from a local zone within the Churchland pluton, located about 16 km west of Lexington (fig. 34) on U.S. Route 64, 3 km west of the Yadkin River and (2) a quartz-feldspar porphyry called leopardite, from the Belmont Springs or Belmont Avenue area in the eastern part of Charlotte, N.C. The leopardite is a white rock lineated by black rodlike aggregates of iron and manganese oxides that appear as black spots on surfaces broken across the grain (lineation) of the rock.

Slate and flagstone have been quarried sporadically in the Carolina slate belt, beginning in 1756 at Hillsborough, northeast of the Charlotte quadrangle, but demand was slight until 1960. Since then a few small quarries have been producing flagstone and slate products. Slightly metamorphosed thin-bedded argillite has

been quarried as flagstone at several localities in the Carolina slate belt; one of the quarries, in southeastern Davidson County (see fig. 34, loc. 23), is still active. Slate has been quarried east of Lexington (fig. 34). Favorable sites for flagstone depend on a combination of even, closely spaced bedding and an absence of crosscutting cleavage, such as is found in certain argillite layers. Such layers have a high potential for additional resources of flagstone.

SAND AND GRAVEL

Alluvial sand and gravel is a potential resource along most streams in the area that are large enough to have formed a flood plain. Sand and gravel have been produced from the Broad River and tributaries in the southwest part of the quadrangle; Buffalo Creek, Beaver Creek, and Fish Creek in the vicinity of the Kings Mountain belt; Long Creek north of Gastonia; Clark Creek between Lincolnton and Hickory; Dutchman's Creek and other tributaries of the Catawba River northwest of Charlotte; and the Yadkin River and many of its tributaries in the eastern part of the quadrangle. Large amounts of sand and gravel are obtained by screening alluvium dredged during the straightening and deepening of stream channels. Such material is stockpiled as levees until needed. The value of sand and gravel produced in the quadrangle through 1978 is about \$50 million.¹

Sites of active mining of sand and gravel, as of 1976, are shown by McDaniel and McKenzie (1976). Many sites are adjacent to larger communities, but Anson County, which has the largest production of any of the counties of the Charlotte quadrangle, is one of the least populous counties in the area, located 25 mi (40 km) or more from important urban centers (see DeYoung and Lee, this volume). Evidently the production from Anson County was transported to urban centers. The next largest production, from Davidson County, is less than one-tenth the production from Anson County. The potential for sand and gravel resources is excellent along streams distant from urban centers that have not been previously utilized because of their locations. It is likely that future supplies will be transported to population centers from distant sites.

The felsic plutonic rocks and quartzose gneisses and schists of the Charlotte, Kings Mountain, Inner Piedmont, and Blue Ridge belts are all especially good sources of alluvial sand and gravel (D'Agostino and Gair,

¹Value of sand and gravel production as reported on a county basis has been \$141.8 million to date, but 64 percent (\$91 million) of that production came from Anson County, and all was from outside the Charlotte quadrangle boundary, mostly or entirely from the Coastal Plain.

in Goldsmith, Horton, and others, 1986). The largest streams in these belts are likely to contain large amounts of sand and gravel along their courses. The large ringlike syenite body just west and southwest of Concord in the Charlotte belt (Goldsmith, Horton, and others, 1986) provides large amounts of residual gravel obtained by washing and screening weathered bedrock. Other plutonic rock units might someday become similar sources of residual gravel. Interfluvial areas overlying plutonic rocks in the Charlotte belt may be particularly favorable locations.

ALLUVIAL CLAY AND SILT

Large amounts of clay and silt used in the manufacture of brick, pipe, and tile have been derived from fine-grained alluvial deposits and are commonly used in combination with crushed mudstone (argillite or phyllite) from the Carolina slate belt. Alluvial clay and silt is mined from flood plains and stream bottoms of several of the larger streams in the area. Varying amounts of organic material are present. Prior to 1920, larger valley bottoms were the major source of clay in large clay-blending plants for local use; however, quality was not consistent. Present practice in the area is to control quality by blending clays from different sources and to restrict the organic material in alluvial clay and silt to 20

percent of total content. Several large reservoirs in the area have a potential for future supplies of such clay and silt, but environmental constraints will probably prevent the dredging of such material from reservoirs in the foreseeable future. Ultimately, however, it may become necessary to dredge parts of the reservoirs to keep them from filling up completely, and this dredging would greatly increase resources of clay and silt.

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DISTRIBUTION OF REPORTED MINERAL PRODUCTION

By JOHN H. DEYOUNG, JR., and MICHAEL P. LEE

INTRODUCTION

Historical records of mineral production have been frequently cited in regional mineral-resource-assessment studies, but few comprehensive studies of the distribution of cumulative mineral production from areas smaller than nations or states and provinces have been done. This report analyzes the quantity and value of past mineral production from the Charlotte 1°×2° quadrangle. It discusses the distribution of reported production of mineral raw materials from the Charlotte quadrangle through 1978, by commodity and by county.

The results of the study have been published separately (DeYoung and others, 1985). The study of mineral production complements studies of geology, geochemistry, geophysics, and mineral deposits that have been used in a mineral-resource assessment of the quadrangle and that can be used when interpreting the assessment. It provides historical information that may be a guide to future mineral production. This information is a yardstick by which resource assessments in different parts of the quadrangle and from other areas can be measured. Portrayal of past production in a graphic or tabular format shows the relative importance (in terms of reported values) of cumulative production of the mineral raw materials. In complementing other reports of the CUSMAP program, this study shows how past production has been areally distributed relative to geologic features. Finally, this is a pilot study of the use of past production data to aid in mineral-resource assessments.

Essential concerns for a study of past mineral production are the availability of data and suitable methods of analyzing the data. The desirability of a map format to present results to users of CUSMAP products influenced selection of the method of analysis. Small-scale maps of the Charlotte quadrangle were used to show the distribution by county of past production of individual mineral commodities. Production data are chiefly those reported by the U.S. Bureau of Mines (USBM) by county and by State; if county data have not been published because of their proprietary nature, data were obtained from the USBM canvass reports. These data were aggregated into cumulative totals so that proprietary information

would not be released. The data pertain to the period from about 1900 through 1978.

The method of analysis selected for this study is the unit-regional-value technique developed by Griffiths (1969) and used by him and his colleagues at The Pennsylvania State University to investigate the geographic distribution of mineral production so that its relationship to geology could be assessed for a number of countries (Griffiths, 1978). Computer programs (the COMOD programs), written by Griffiths and his coworkers (Labovitz and others, 1977), had been used in the CUSMAP program to analyze past production data from the Sherbrooke-Lewiston 1:250,000 quadrangle in Maine, New Hampshire, and Vermont (Bawiec and Turner, 1983). The unit-regional-value technique provides a system for classifying mineral-production data according to location (area) where production took place, year of production, and mineral commodity as listed in a standard set of commodity names.

The concept of mineral-production-value per unit area as a measure of mineral resources available in the Earth's crust was used by Blondel and Ventura (1954) and has been used in later reports at 5-year intervals (see, for example, Callot, 1980). Joralemon (1976, p. 182, 249), a mining engineer, used studies of copper production per acre as the basis for a 1916 New York Stock Exchange listing of Calumet and Arizona stock and in property valuations done for the Bureau of Internal Revenue in 1921 to comply with the percentage depletion provision of the income tax law. An even earlier use of production per unit area was made in comparing bullion production per square mile of States in the Second Annual Report of the U.S. Geological Survey (King, 1882, p. 400-401). Thinking of mineral resources in terms of the ability of an area of land to yield mineral raw materials is analogous to comparing crop yields in agriculture. Consideration of the mineral production potential of a tract of land in land-use planning in the United States predates current debates about alternative land uses (Goetz, 1983, p. 12).

Because this study was done to supplement and support an assessment of mineral resources in the Charlotte quadrangle, it is concerned only with minerals extracted from that area and not with the production of processed

mineral raw materials such as cement or aluminum, which may have used minerals that originated outside the quadrangle. When using past production reports, as in this study, the effect on the production data of nongeologic factors, such as demand for minerals and reporting procedures, has been considered.

There are several possible ways of analyzing mineral-production data that have not been attempted here. Estimates of mean and variability of unit regional value for counties in North Carolina and South Carolina can be compared with unit regional value for other States and regions. Such comparisons require consistency, not found in published studies, in years of data collection and definitions of commodity categories. A comparison of unit regional value and unit regional weight for counties in North Carolina and South Carolina, with some areal measure of the different lithologies in the counties, may be used to test the importance of geology to mineral production value when compared with other variables. Other variables, particularly population, may be treated as a time series and compared with a time series of mineral production.

The next two subsections of this report describe the collection of mineral-production data and the analysis of the data by the unit-regional-value technique. These two steps were not entirely separate or sequential. The need to organize past production data from several types of reports into a format for analysis by computer programs involved checking annual totals of county data, ascertaining that all reports for a commodity are in terms of the same material, and, if possible, estimating production for years lacking records. The method of analysis dictated the format for data collection, and the interim analytical results sometimes dictated collection of additional data or a second look at sources from which data had already been collected.

COLLECTION AND ORGANIZATION OF DATA

DATA-FILE STRUCTURE

Because the analysis of production data for the Charlotte quadrangle used the COMOD computer programs (Labovitz and others, 1977), the data-file structure of those programs was the basis for organizing the production data. For production records to indicate *when*, *where*, and *how much* of *what* was produced, a file structure having the following five elements was used: year of production, location (county and State) of production, physical quantity produced, value of amount produced, and mineral commodity produced.

YEAR OF PRODUCTION

The year of reported production may indicate the year of mining, processing, or sale. It is important that the definition be consistent from year to year for each mineral commodity so that each unit of production is counted only once. Data were collected for production through the 1978 calendar year. The earliest years for which production figures were gathered ranged from 1804 for gold to 1956 for vermiculite.

LOCATION OF PRODUCTION

Counties were the basic areal unit for the unit-regional-value study because they represent units of known size (ranging from 557 to 2,152 km²) for which many reported production data are available and for which other production data can be readily calculated or estimated (fig. 35). Collection of data for alternative areas such as mapped geologic formations or grid systems is extremely time consuming in those cases where point locations of individual mines, pits, or quarries are known and, if only county totals remain from original canvasses, may not be possible.

Each record of reported production was assigned to 1 of the 27 counties of North Carolina or 4 counties of South Carolina that are totally or partially within the boundaries of the Charlotte quadrangle. These 31 counties are referred to in this report as "Charlotte quadrangle counties." The inclusion of counties that are only partially within the Charlotte quadrangle is necessary to cover all production in the quadrangle consistently because some data are reported only as county totals. Some other production data are reported only as State totals. To incorporate these data into the analysis, data on reported production were collected for each of the 100 counties of North Carolina and 46 counties of South Carolina. Reported production that did not indicate the county of origin was assigned an undistributed category for the appropriate State.

The inclusion of any county that is totally or partly within the boundaries of the Charlotte quadrangle in this analysis has introduced some production data that are from areas not considered in other reports in the Charlotte CUSMAP folio. The 31 Charlotte quadrangle counties considered cover 38,397 km², compared to the 19,950 km² covered by the Charlotte quadrangle. If significant production from border counties has taken place outside the quadrangle boundaries, this has been noted in the text description for each mineral commodity. The principal examples are gold from Lancaster County, S.C., and sand and gravel from Anson County, N.C.

A possible problem in using political divisions as areal units for data collection is that boundaries and names of these divisions may have changed. In this study, only one

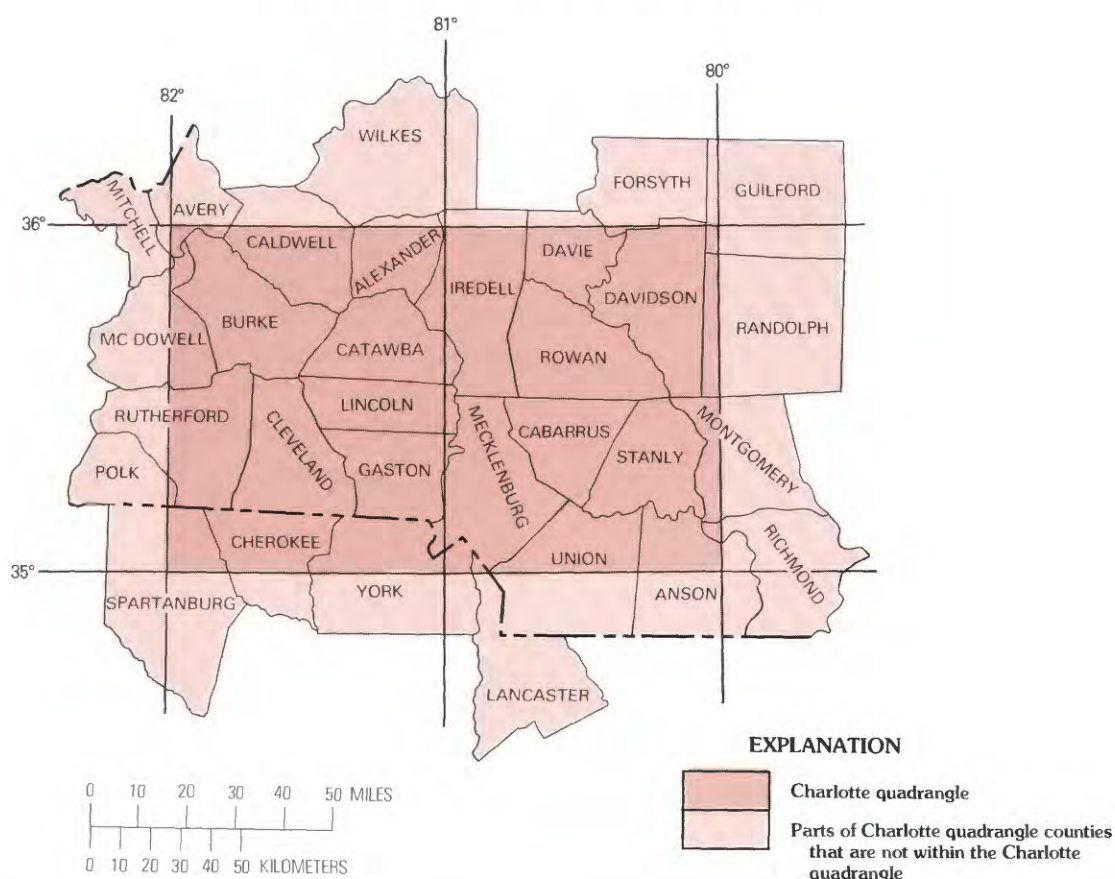


FIGURE 35. — Index map of the 31 Charlotte quadrangle counties of North Carolina and South Carolina that are entirely or partially within the Charlotte quadrangle.

such situation was recognized, and that was outside the Charlotte quadrangle (the formation of McCormick County, S.C., in 1916 from parts of Abbeville, Edgefield, and Greenwood Counties¹).

PHYSICAL QUANTITY PRODUCED

The amount of production and units of measurement were collected. All production measures were converted to metric units in the COMOD programs to calculate cumulative totals and production per unit area (grams for gold and silver; metric tons for all other commodities).

The USBM reports of crude mineral production from North Carolina and South Carolina, used as the primary source of the mineral production information for this study, list produced quantities at several stages of processing, including ore, metallic content, or refined metal produced or sold. In this study, reported produc-

tion of construction materials, nonmetallic minerals, coal, and peat represents material sold. Chromium ore, iron ore, manganese ore, thorium ore, uranium ore, vanadium ore, and zirconium ore are reported as tons of ore or mineral concentrate. Tungsten and titanium are reported as tons of tungsten trioxide (WO_3) and titanium dioxide (TiO_2), respectively, contained in concentrates. Other metals, including precious metals, are reported as the recoverable metal (element, not oxide) in ores.

VALUE OF MATERIAL PRODUCED

The reported value was collected for each production record; all values for a given year were reported in then-current U.S. dollars and were converted to 1967 constant U.S. dollars by the COMOD programs using the Wholesale Price Index.

In some cases, reported values are the actual sales values of the mineral raw materials or sales values as estimated by the USBM; in other cases, data sources provide an estimate of value calculated by multiplying an average sales price at the time of production by the reported quantity. In either case, the reported value is

¹Production of precious metals from the Dorn mine, which was reported from Abbeville County prior to 1916, was reassigned to McCormick County and appears in this study only in the category on summary graphs labeled "South Carolina counties entirely outside the Charlotte quadrangle."

based on the selling price and includes returns to the factors of production such as capital (including equipment and machinery) and labor, in addition to the value accruing to the mineral resource (what economists call "economic rent").²

Physical units are a more satisfactory measure than dollar value for analyzing the production of each mineral commodity, but the value of production provides a common denominator for adding and comparing production statistics of several commodities. Summing grams of gold and metric tons of iron ore has little, if any, usefulness. Studies of production of energy commodities often convert physical measures (tons, cubic feet, barrels) to heat values, such as British thermal units; monetary values, with all their flaws, seem the best method for aggregating nonfuel mineral statistics.

CLASSIFICATION OF MINERAL COMMODITIES

The list of mineral commodity names used in the COMOD programs (Labovitz and others, 1977, p. 497-498, 511-514) can be expanded to include any commodities produced in a given region. Reported commodity names have been grouped and, if necessary, transformed by the computer programs into 1 of 77 standard commodity names.

Reported production for 37 standard commodities in 6 commodity categories (table 7) has been included in the analysis of mineral production from the Charlotte quadrangle, but 9 of these commodities (marked by asterisks) have been produced completely outside the boundaries of the Charlotte quadrangle. They are included to complete the production records for North Carolina and South Carolina, with which production from the undistributed categories are compared. The numbers in parentheses following the name of each commodity and commodity category are the codes used in the COMOD program. These codes are used in the tables and text of this report as an integral part of the commodity and commodity category names.

Production data for two of the standard commodities listed in the COMOD program were not considered in this analysis: cement (102) and mineral pigments (415). Raw materials used in the production of these commodities were reported under other commodity names (for example, limestone for cement production was included in stone (108) and iron-oxide minerals for pigment use were included in iron ore (310)). Inclusion of cement and

mineral-pigment production statistics would have constituted double-counting and also introduced value added beyond the production of mineral raw materials.

TABLE 7.—*Names and numerical codes of mineral commodities and mineral commodity categories for which production was reported in North Carolina and South Carolina*

[Production of all commodities except those marked with asterisks has been reported from the Charlotte quadrangle counties. The numbers in parentheses following the name of each commodity and commodity category are the codes used in the COMOD program]

Construction materials (100)
Asbestos (101)
Common clay and shale (103)
*Gypsum (105)
Mica (106)—includes scrap and sheet mica
Sand and gravel (107)—includes some industrial sand (421)
Stone (108)—includes dimension and crushed stone; includes some lime (413)
Fuels (200)
*Bituminous coal (203)
*Peat (209)
Uranium ore (211)
Metals—excluding gold and silver (300)
*Chromium ore (307)
Copper (309)
Iron ore (310)
Lead (311)
Lithium (312)
Manganese ore (314)—includes metallic ores and manganese brick clay
*Tantalum (319)
Thorium ore (320)—includes rare earths
Tin (321)
Titanium (322)
*Tungsten (323)
*Vanadium ore (324)
Zinc (325)
*Zirconium ore (326)
Nonmetallic minerals (400)
Kyanite (401)
Barite (402)
Kaolin and specialty clays (406)
Feldspar (408)
Gemstones (411)
Graphite (412)
Lime (413)—some reported as stone (108)
*Phosphate rock (417)
Pyrite (419)
Industrial sand (421)—some reported as sand and gravel (107)
Talc (424)
Vermiculite (425)
Precious metals (500)
Gold (502)
Silver (504)
All commodities (600)—sum of the five commodity categories

²The value of mineral resources in the ground represents only a portion of the values of mineral production presented in this analysis. For some mineral construction materials, like sand and gravel, the selling price is, in some instances, almost wholly attributable to production cost, and the in-the-ground resource value is negligible.

DATA SOURCES

Data sources were selected to obtain complete geographic coverage for as many years as possible without having overlapping records and with consistent terminology. The major source of data was the microfilm records of USBM and its predecessor in U.S. mineral industry canvass work, USGS. The USBM data are reported in the annual "Minerals Yearbook" and are in a format not readily usable for cumulative production analysis. However, county production data often can be obtained from the microfilms in which data are more detailed than those published in "Minerals Yearbook." The annual data for individual mining operations are proprietary, but when compiled for geographic regions, as in the "Minerals Yearbook" annual totals, or for a number of years as in this report, they are not compromised in publication. The microfilm records used in this study include production through 1978. The earliest data available on the microfilms are for about 1900, but the data coverage for different commodities is for different time spans between 1900 and 1978.

Other sources of mineral production statistics were consulted to supplement the data from the microfilm files for specific commodities, time periods, or geographic regions, as follows:

1. Published production statistics from "Minerals Yearbook" (USBM, 1933-81) and its predecessor volumes (USGS, 1883-1927; USBM, 1927-34) are less detailed than those in the microfilm records, but some published reports contain records of production that do not exist in the microfilms.

2. Reports of production in the North Carolina Economic Papers Series (Pratt, 1901-08; Pratt and Barry, 1911; Bryson, 1937) contain many of the same records as the Federal Government publications but have additional detail on some North Carolina commodity production for the period around 1900.

3. Reports on precious metal production in the United States prepared by the Director of the Mint (U.S. Bureau of the Mint, 1882-83, 1884-1906) include sections on the Appalachian States, some of these sections contain tables showing production of gold and silver by county. For the years 1881 to 1892, the reports contain information only on the dollar value of precious-metal production from each county (or, for some years, groups of counties), and amounts of gold and silver were estimated by using historical proportions for each county for the period 1893 to 1905. From 1881 to 1888, when production statistics for some counties were combined in the Mint reports, county production was estimated by apportioning the totals among producing counties on the basis of their production from subsequent years. The Mint data were used for gold and silver production for the years

1881 to 1905; USGS and USBM data were used for 1906 to 1978.

4. A report on gold deposits in the southern Piedmont (Pardee and Park, 1948, p. 31-32) provided State totals for the years before 1881 (1804-80 for North Carolina and 1826-80 for South Carolina). These data were assigned to the "undistributed category" of the appropriate State.

5. Records of coal production in North Carolina (Reinemund, 1955) were compiled to complete the North Carolina-South Carolina data set. No coal production was reported for the Charlotte quadrangle counties.³

6. A summary of chromium production in North Carolina (Thayer and Hobbs, 1968, p. 373) was used to supplement microfilm data on chromium production.

7. A report concerning metallic mineral deposits of the Carolina slate belt (Carpenter, 1976, p. 16-21) was used to check and supplement data from USBM microfilms and publications.

8. Assistance was obtained from USBM commodity specialists for lithium (J.P. Searls, oral commun., 1982) and phosphate rock (W.F. Stowasser, oral commun., 1982), particularly regarding production statistics for North Carolina counties that were not available from other sources.

Additional production information is available in geological reports on deposits and mining districts, several of which refer to mine production in the early 19th century. However, a complete review of all such reports was not possible in the time available for the study; furthermore, such sources were not used because the addition of production data only from selected mines or years would have introduced inconsistency to the data used and confused the analysis.

Some 14,545 production records on value and physical units were collected for North Carolina and South Carolina (table 8); of these, 5,314 (37 percent) were from Charlotte quadrangle counties. Production data are not available for all commodities for identical time spans. For example, precious-metal data were obtained for years since 1804 (available on a county-by-county basis only since 1881), whereas data for construction materials were obtained only for 1887 to 1978 (for example, data on sand and gravel were available only from 1907 to 1978) (table 9).

Of the number of production records collected for Charlotte quadrangle counties, 56 percent are for construction materials (100), 30 percent for precious metals (500), 9 percent for nonmetallic minerals (400), and 5 percent for metals (300). Records for fuels (200) make up

³Records of production of mineral fuels were not available in USBM microfilm files because the responsibility for statistics of these commodities was transferred to the U.S. Department of Energy in 1977.

TABLE 8.—*Distribution of mineral production records by county and by mineral commodity for the Charlotte quadrangle*
 [Number of records. —, no data. The numbers in parentheses following the name of each commodity and commodity category are the codes used in the COMOD program]

	Construction materials (100)	Fuels (200)	Metals (300)	Nonmetallic minerals (400)	Precious metals (500)	All commodities (600)
Charlotte quadrangle counties						
<i>North Carolina:</i>						
Alexander	49	—	1	12	—	62
Anson	105	—	—	23	13	141
Avery	159	—	35	65	—	259
Burke	60	—	19	4	84	167
Cabarrus	90	—	6	2	86	184
Caldwell	80	—	11	1	60	152
Catawba	82	—	1	3	69	155
Cleveland	162	—	57	37	25	281
Davidson	109	—	13	2	57	181
Davie	51	—	—	4	2	57
Forsyth	86	—	—	2	—	88
Gaston	111	—	19	37	83	250
Guilford	133	—	3	15	66	217
Iredell	74	—	—	1	23	98
Lincoln	90	—	8	5	35	138
McDowell	89	—	15	6	69	179
Mecklenburg	60	—	5	1	87	153
Mitchell	238	3	12	129	—	382
Montgomery	101	—	—	9	107	217
Polk	56	—	—	—	50	106
Randolph	61	—	3	13	85	162
Richmond	40	—	—	13	—	53
Rowan	233	—	13	—	82	328
Rutherford	92	—	18	3	88	201
Stanly	56	—	—	1	80	137
Union	64	—	1	—	90	155
Wilkes	58	—	—	1	5	64
Total	2,589	3	240	389	1,346	4,567
<i>South Carolina:</i>						
Cherokee	103	—	20	48	36	207
Lancaster	62	—	—	2	93	157
Spartanburg	111	—	1	20	61	193
York	89	—	9	24	68	190
Total	365	—	30	94	258	747
Total Charlotte quadrangle counties.....						5,314
All counties						
<i>North Carolina:</i>						
Charlotte quadrangle counties	2,589	3	240	389	1,346	4,567
Other North Carolina counties	4,504	174	182	785	401	6,046
Undistributed	272	1	6	92	90	461
Total	7,365	178	428	1,266	1,837	11,074
<i>South Carolina:</i>						
Charlotte quadrangle counties.....	365	—	30	94	258	747
Other South Carolina counties	1,963	15	28	231	248	2,485
Undistributed	104	—	3	51	81	239
Total	2,432	15	61	376	587	3,471
Grand total						14,545

about 0.1 percent of production records (table 8), and these records pertain entirely to areas outside the quadrangle.

The distribution of value of total mineral production among Charlotte counties, other counties, and undistributed amounts for North Carolina and South Carolina is shown in figure 36. The pie diagram for the State with

the larger production is a standard size, and the diagram for the State having the smaller production is scaled so that the area is proportional to total production indicated for the State having larger production. The category labeled "Statewide" (not attributed to specific counties) is important because it shows what percentage of cumulative production is undesignated with respect to county

TABLE 9.—*Major sources of mineral production statistics*

[Includes major data sources (see subsection on collection and organization of data); additional references were used for specific commodities and years; data for all commodities and (or) years are not always complete in sources used. NCEP, North Carolina Economic Papers (Pratt, 1901-08; Pratt and Barry, 1911; Bryson, 1937); USBM, U.S. Bureau of Mines; USGS, U.S. Geological Survey; Mint, U.S. Bureau of the Mint. Microfilm records of canvasses reported in USBM (1927-34, 1933-81) and USGS (1883-1927). The numbers in parentheses following the name of each commodity and commodity category are the codes used in the COMOD program]

Commodity group	Time period of coverage	Source
Construction materials (100)	1898-1936 1906-78 1887-1923	NCEP. USBM (microfilm). USGS (1883-1927).
Fuels (200): Coal (203) Other fuel minerals	1840-1949 1900-22	Reinemund (1955). NCEP and USGS (1883-1927).
Metals—excluding gold and silver (300)	1893-1911 1887-1923 1906-78	NCEP. USGS (1883-1927). USBM (microfilm).
Nonmetallic minerals (400)	1867-1923 1906-78	USGS (1883-1927). USBM (microfilm).
Precious metals (500): Gold (502)	1804-80 1881-1905 1906-78	Pardee and Park (1948). Mint (1882-1906). USBM (microfilm).
Silver (504)	1881-1905 1906-78	Mint (1882-1906). USBM (microfilm).

of origin. In cases where this category is large, the indicated distribution of production among Charlotte quadrangle and other counties may not reflect very well the total historical production.

Figure 36 provides information on the amounts of reported production that were assigned to specific counties, but it presents a comparison of production from areas of unequal size. Cumulative reported production per unit area (unit regional value, or urv) for areas of North Carolina and South Carolina in each of the six commodity categories is shown on bar graphs in figure 37. The urv for each State is shown for (1) the 31 Charlotte quadrangle counties, (2) counties that are entirely outside the Charlotte quadrangle boundaries, (3) undistributed cumulative production in North Carolina and South Carolina that is not attributed to specific counties, and (4) the entire State (the sum of the first three categories).

PROBLEMS OF INCOMPLETE DATA

Some reports of production did not contain enough information to complete the required elements in the data file. The major problems and assumptions resulting from such incomplete data are listed below. The effect of incomplete data, for whatever reason, is that calculated

mineral production totals are conservative; that is, the reported value is less than the true value.

Information that was not reported.—If companies or individual operators did not report their mineral production, it was not included in this analysis. With very few exceptions, reports on all USBM surveys have been voluntary (National Research Council, 1982, p. 30-31). The difference between reported and actual production for some periods may be significant, especially for precious metals or gemstones. Therefore, this report is, in the strictest sense, an analysis of *reported* past production of mineral commodities.

Lack of records for early years of production.—The earliest years for which production reports were incorporated into the data file are indicated in the text descriptions for individual commodities. For several important commodities, including stone and sand and gravel, the tonnage of material that was produced before reported statistics were available represents a very small part of the cumulative totals.

County location not specified.—Some production reports indicated only the State from which the material was produced; others listed amounts of production for groups of counties. In some of those cases, other production reports and geological information provided guidance in assigning the amounts of production to specific counties; in other cases, the production was classed as undistributed.

Units of production not clearly stated.—The few early production reports of some commodities did not distinguish between short tons and long tons. More recent production records generally cite the units used. In those few early reports where no other information was available, "tons" were assumed to be short tons.

Reports of "miscellaneous" or "other" production.—The few cases of production statistics classified as "miscellaneous" or "other" were not included in this compilation. For those commodities reported as a "combined value" figure in the "Minerals Yearbook," individual production records were obtained from USBM microfilm files.

UNIT-REGIONAL-VALUE ANALYSIS

After production statistics were compiled on tabulation sheets, they were entered into a computer file by using a format that accommodated all necessary information about the five elements of the file structure discussed earlier. The computer file of raw data was grouped first by commodity, next by year, and finally by State and county. Annual State production totals were calculated for several commodities (for example, sand and gravel, stone, gold, and silver) and compared with published State totals to check for keypunching errors.

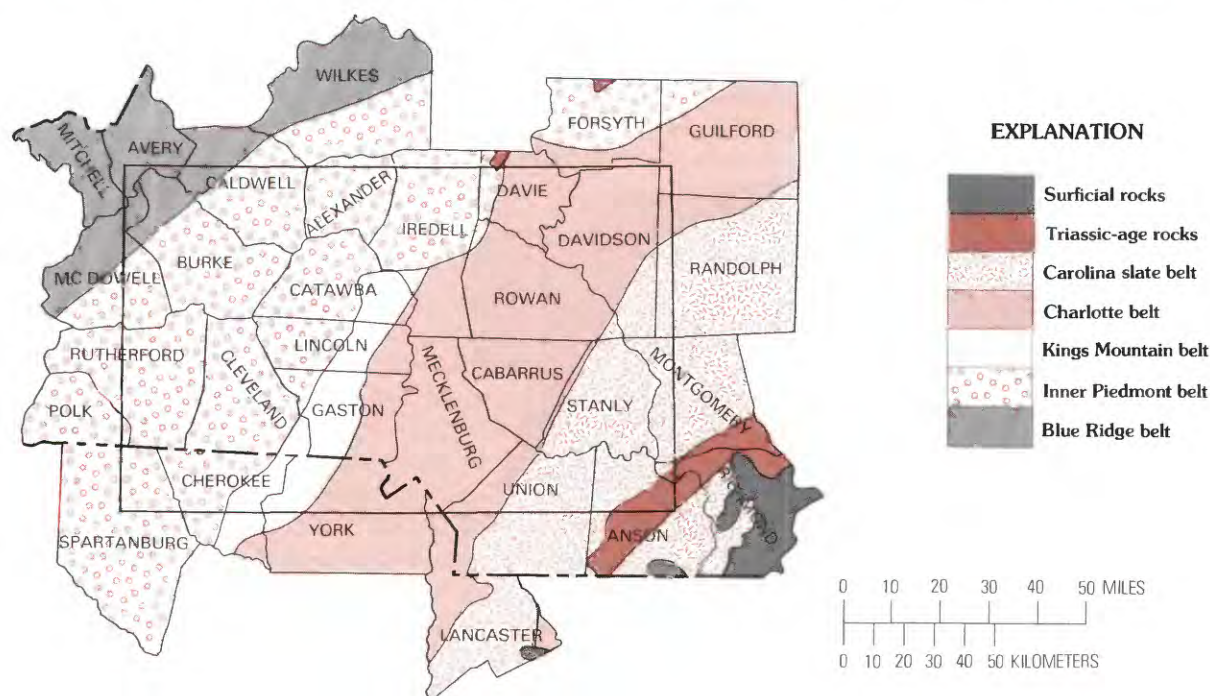


FIGURE 39.—Lithotectonic belts in the Charlotte quadrangle. Contacts are simplified to show the general location of major geologic units; plutonic rocks are not shown. Modified from Goldsmith and others (1982), King and Beikman (1974), and Overstreet and Bell (1965).

counties have reported mineral production of two or more of the commodities listed in the construction materials category (fig. 40).

Construction materials have the highest urv of the five commodity categories for Charlotte quadrangle counties in North Carolina (\$23,800/km²) and South Carolina (\$16,100/km²). These values are about 150 percent more per unit area than the rest of North Carolina and about 75 percent more than other counties in South Carolina (fig. 37A).

ASBESTOS (101)—TIME PERIOD OF PRODUCTION RECORDS:
1901 TO 1943

Reported production from Avery County, N.C., is from the Spruce Pine district (Brobst, 1962, p. 22), outside the Charlotte quadrangle.

COMMON CLAY AND SHALE (103)—TIME PERIOD OF PRODUCTION RECORDS: 1898 TO 1978

Common clay and shale includes "clay" and "raw clay" used for structural clay products such as brick and drain tile and clay used to produce bloated lightweight aggregate in Stanly County, N.C. These materials are classified as construction materials, whereas kaolin and specialty clays are classified as nonmetallic minerals. Most of the reported production is from counties in the Charlotte belt or the Carolina slate belt. Reported production from

Avery, Guilford, Mitchell, Randolph, and Richmond Counties, N.C., and Lancaster County, S.C., is probably from deposits that are outside the Charlotte quadrangle. Some of this material has been produced from ephemeral clay pits in stream or river banks; such pits are not necessarily shown in the location map of clay production for the Charlotte quadrangle (D'Agostino and Rowe, 1986). For example, Gaston County, N.C., has reported clay production but has no reported locations of producers.

MICA (106)—TIME PERIOD OF PRODUCTION RECORDS: 1897 TO 1978

Production statistics for scrap, sheet, and flake mica are included in mica. Sheet mica is not a construction material, but because separate data on sheet and scrap mica are not uniformly available, all mica production has been placed in the construction materials category. Production data attributable to specific counties were collected as early as 1900. Production for 1897 to 1899 and for some later years has been reported as State or district totals; in these cases, estimated amounts have been attributed to specific counties. Reported production of mica (muscovite or phlogopite) is from pegmatites, weathered granites, and saprolite of the Blue Ridge belt (Spruce Pine district), Inner Piedmont belt, and Kings Mountain belt. Small amounts of reported production in

TABLE 10.—*Value of reported mineral production through 1978 by commodity and commodity category from the 31 Charlotte quadrangle counties*
[Items may not add to totals shown because of rounding]

Commodity category (code) (percentage of all commodities)	Commodity (code)	Reported production (1967 U.S. dollars)	Percentage of category total
Construction materials (100) ¹ (74.3%)	Stone (108)	624,000,000	71.9
	Sand and gravel (107)	142,000,000	16.3
	Mica (106)	66,500,000	7.7
	Common clay and shale (103)	35,200,000	4.1
	Asbestos (101)	31,800	.004
	Total	867,000,000	100.0
Fuels (200) ² (0.00008%)	Uranium ore (211)	969	100.0
Metals—excluding gold and silver (300) ³ (10.0%)	Lithium (312)	100,000,000	85.8
	Iron ore (310)	8,410,000	7.2
	Thorium ore (320)	3,700,000	3.2
	Titanium (322)	2,620,000	2.2
	Copper (309)	1,380,000	1.2
	Tin (321)	280,000	.2
	Manganese ore (314)	65,100	.06
	Zinc (325)	58,100	.05
	Lead (311)	25,500	.02
	Total	117,000,000	100.0
Nonmetallic minerals (400) ⁴ (13.4%)	Feldspar (408)	123,000,000	78.6
	Kyanite (401)	10,800,000	6.9
	Kaolin and specialty clays (406)	7,700,000	4.9
	Industrial sands (421)	5,660,000	3.6
	Vermiculite (425)	3,890,000	2.5
	Barite (402)	1,970,000	1.3
	Talc (424)	1,770,000	1.1
	Lime (413)	894,000	.6
	Pyrite (419)	724,000	.5
	Gemstones (411)	108,000	.07
	Graphite (412)	7,400	.005
	Total	157,000,000	100.0
Precious metals (500) ⁵ (2.3%)	Gold (502)	25,600,000	97.3
	Silver (504)	722,000	2.7
	Total	26,400,000	100.0
All commodities (600) ⁶ (100%)	Grand total	1,170,000,000	

¹Reported production from Anson, Forsyth, Guilford, Mitchell, Polk, Randolph, Richmond, and Wilkes Counties, N.C., and Lancaster County, S.C., is probably from outside the Charlotte quadrangle.

²Reported production from Mitchell County, N.C., is from outside the Charlotte quadrangle.

³Reported production from Avery, Caldwell, Guilford, and Mitchell Counties, N.C., and Spartanburg County, S.C., is probably from outside the Charlotte quadrangle.

⁴Reported production from Anson, Davie, Forsyth, Guilford, Mitchell, Randolph, Richmond, and Wilkes Counties, N.C., and Lancaster and Spartanburg Counties, S.C., is probably from outside the Charlotte quadrangle.

⁵Reported production from Anson, Guilford, Polk, and Wilkes Counties, N.C., and Lancaster and Spartanburg Counties, S.C., is probably from outside the Charlotte quadrangle.

⁶All or most reported production from Anson, Forsyth, Guilford, Mitchell, Polk, Randolph, Richmond, and Wilkes Counties, N.C., and Lancaster and Spartanburg Counties, S.C., is probably from outside the Charlotte quadrangle.

Alexander, Burke, Caldwell, Catawba, Davie, Gaston, Iredell, Lincoln, and Rutherford Counties, N.C., are from deposits not shown on the location map of mica and feldspar production for the Charlotte quadrangle (D'Agostino and Rowe, 1986). Reported mica production from Guilford, Mitchell, and Wilkes Counties, N.C., is probably from outside the Charlotte quadrangle.

SAND AND GRAVEL (107)—TIME PERIOD OF PRODUCTION RECORDS: 1907 TO 1978

Reported production includes sand and gravel for all construction material uses and for some industrial mineral uses. Olivine produced for foundry sands and crushed quartz for industrial mineral uses have been

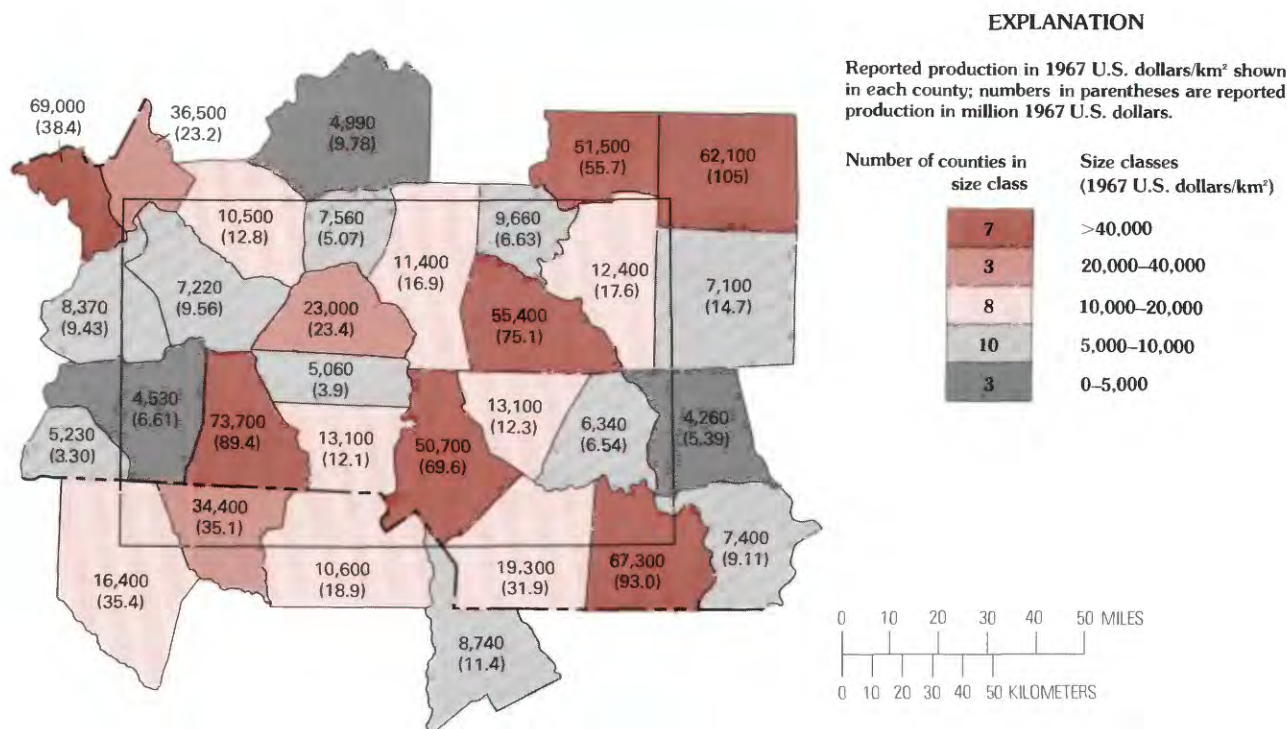


FIGURE 40.—Cumulative reported production for the construction materials (100) category from the 31 Charlotte quadrangle counties. The time period of production, 1868–1978, is for reported mineral production, but production was not necessarily continuous during the period. D'Agostino and Rowe (1986) have indicated past production of common brick clay from

Anson and Rutherford Counties, N.C., but no production was reported for these counties in the data compilation done for this study. For these and other counties that have incomplete records of reported production, totals in this compilation underestimate total production.

classified as industrial sands. Reported production from sand and gravel pits is mostly from counties in the Inner Piedmont belt and the Charlotte belt. Gravel includes friable igneous rock that has been quarried. Reported sand and gravel production from Anson, Avery, Forsyth, Guilford, Mitchell, Montgomery, Polk, Randolph, Richmond, Union, and Wilkes Counties, N.C., and Lancaster County, S.C., is probably from outside the Charlotte quadrangle. Production data include sand and gravel produced by the North Carolina State Highway and Public Works Commission from ephemeral dredging sites not necessarily shown on the location map of sand and gravel production for the Charlotte quadrangle (D'Agostino and Rowe, 1986). Such dredged material includes reported production from Alexander, Davidson, Davie, Stanly, and other North Carolina Counties.

STONE (108)—TIME PERIOD OF PRODUCTION RECORDS: 1889 TO 1978

Stone includes crushed and dimension stone and some stone used for abrasive purposes. The names by which stone production has been reported (abrasive stone, basalt, granite—crushed and dimension, limestone, marble—crushed and dimension, millstones, sandstone—

crushed and dimension, stone—crushed and dimension, and trap rock) may not always agree with the geologic terms that describe the quarried rock. For example, production of crushed igneous rock containing feldspar and quartz has been reported as sandstone. Material classified as limestone for construction material use, especially in recent years, also includes limestone used for agricultural purposes and for cement production. In records from earlier years, agricultural lime and limestone have been reported as lime. Reported production from Avery, Forsyth, Guilford, Mitchell, Polk, Randolph, Richmond, and Wilkes Counties, N.C., and Lancaster and Spartanburg Counties, S.C., is probably from deposits that are outside the Charlotte quadrangle. Production data include crushed stone produced by the North Carolina State Highway and Public Works Commission.

FUELS (200)

Of the five commodity groups, the fuels category contributes the least to total reported production for the Charlotte quadrangle counties, and all of that is uranium

from production outside the quadrangle (table 10); as a consequence, the fuels category has the lowest urv (fig. 37*B*). In both North Carolina and South Carolina, fuels production (coal and peat, but no oil or gas) was principally from counties lying entirely outside the Charlotte quadrangle (fig. 36*B*).

URANIUM ORE (211)—TIME PERIOD OF PRODUCTION
RECORDS: 1900 TO 1904

Production of uranium ore (pitchblende) in the Blue Ridge belt was reported in the early 1900's. Most reported production is from the Flat Rock mine in the Brown Mountain Granite in Mitchell County, N.C., and is outside the Charlotte quadrangle. There are no known sources of uranium production in the Charlotte quadrangle.⁶

METALS—EXCLUDING GOLD AND SILVER (300)

Charlotte quadrangle counties have contributed 50 percent of the reported value of metals produced in North Carolina and 23 percent in South Carolina (fig. 36*C*). The 31 Charlotte quadrangle counties in North Carolina and South Carolina produced 194 and 250 percent, respectively, more metal value per unit area than counties outside quadrangle boundaries (fig. 37*C*). The metals category ranks third in reported production for Charlotte quadrangle counties, contributing 10 percent of the total value of mineral production (table 10).

The lack of undistributed production in figure 36*C* can probably be attributed to two factors. The first is that lithium, which has the highest reported value for metals (86 percent of the metals category, see table 10), represents a unique geologic occurrence primarily in two counties in the Kings Mountain belt and entirely within the Charlotte quadrangle. Reported production with no indication of county source was therefore assigned to the appropriate county or counties having a high degree of confidence. Second, few pre-1900 production records, either on a county or State basis, were found for this commodity category from the sources used in this study (fig. 41). Reported metal production, mostly for the years since 1900, is generally attributed to a specific county or counties (fig. 42).

After lithium, the most important commodities in the Charlotte quadrangle counties in the metals category are iron ore, thorium ore, titanium, and copper, which contribute an additional 14 percent of reported produc-

tion value. There has been minor production of tin, manganese ore, zinc, and lead (table 10).

Some metals produced in the Charlotte quadrangle have also been produced elsewhere in North Carolina and South Carolina (for example, copper, titanium, and manganese ore). One important commodity in the State metal totals (tungsten, from North Carolina) has been produced entirely outside the Charlotte quadrangle.

The reported mineral-production value for the metals category understates the actual level of output because of the paucity of quantitative records of production for the middle and late 19th century, when this region was an important producer of iron ore and base metals.

COPPER (309)—TIME PERIOD OF PRODUCTION RECORDS:
1901 TO 1943

Most counties having reported copper production straddle the contact between the Charlotte belt and the Carolina slate belt (Gold Hill shear zone). Reported production for 1901 to 1916 from the Union Copper mine in Rowan County, N.C., accounts for most of the reported production from the Charlotte quadrangle; copper also was produced in the quadrangle during the 1800's, but records by county of most of this production were not available (fig. 41*A*). Reported production from Guilford and Randolph Counties, N.C., is probably from outside the Charlotte quadrangle.

IRON ORE (310)—TIME PERIOD OF PRODUCTION RECORDS:
1883 TO 1974

Iron-ore production took place in the Charlotte quadrangle from the mid-1700's to the late 1800's in "The Old Iron District" in South Carolina (Cherokee and York Counties) and in the Kings Mountain belt (Cherokee Falls synform) and vicinity in North Carolina (fig. 41*B*), but data on this production are not available in the sources used for this compilation. Production reported here (table 10) is from the Cranberry district, Avery and Mitchell Counties, N.C., which is outside the Charlotte quadrangle. As for other commodities, data on production from parts of Charlotte quadrangle counties that are outside the quadrangle are included in this study and have been included in totals for "Charlotte quadrangle counties" because it was not possible to determine production from inside and outside the quadrangle for all counties and for all commodities.

LEAD (311)—TIME PERIOD OF PRODUCTION RECORDS: 1910
TO 1938

The reported production of lead is from the Silver Hill mine (Davidson County, N.C.) and from byproduct production from the Allan Furr mine (Cabarrus County, N.C.) for the year 1936. Most lead production from

⁶Pratt (1904, p. 33; 1905, p. 50) suggests an undisclosed amount of uranium ore mining in Yancey County, N.C. However, because production data were not reported in the sources used by this study, Yancey County cumulative production totals do not contain any uranium ore.

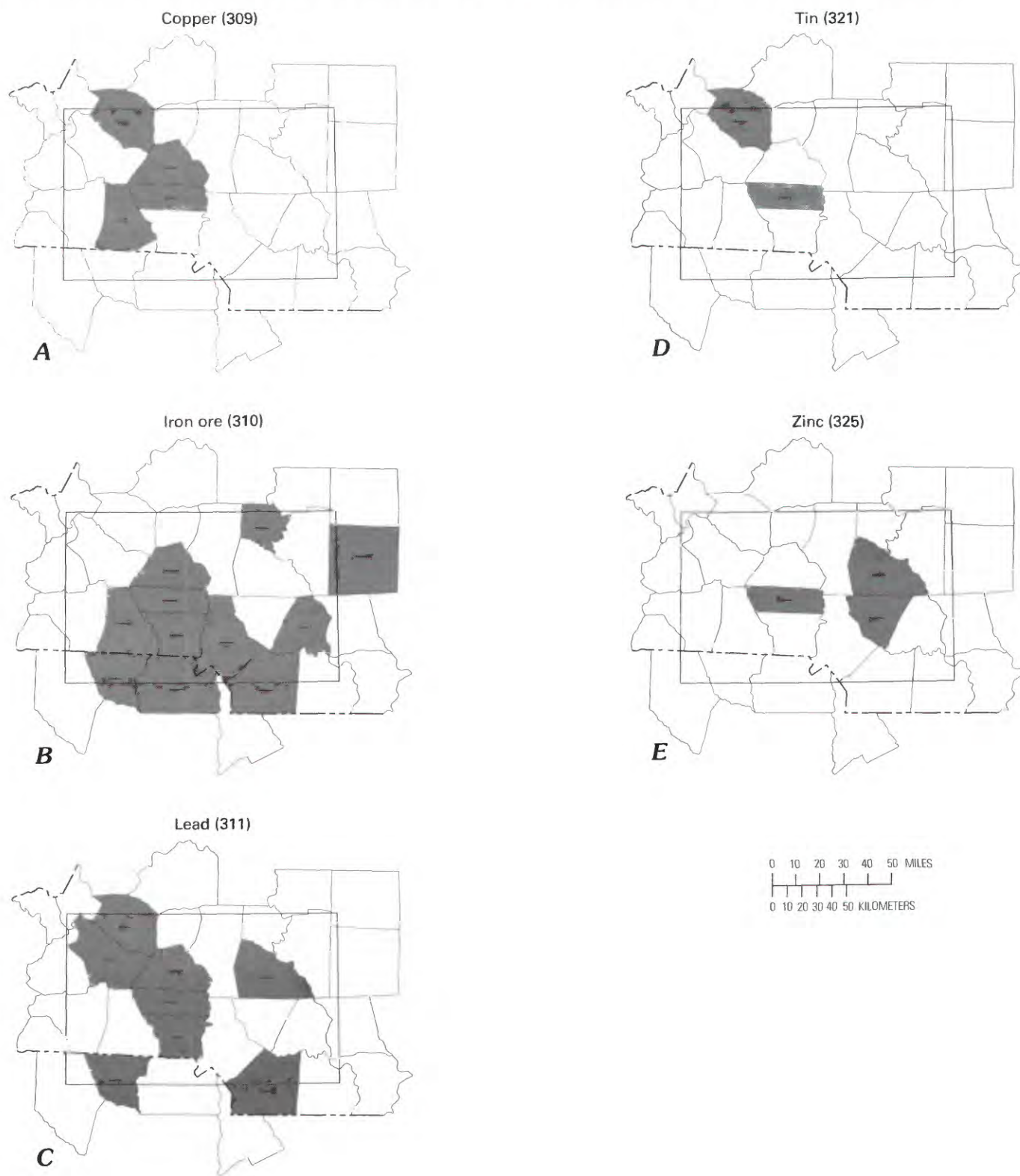


FIGURE 41.—Counties for which past metal production within the Charlotte quadrangle has been identified (D'Agostino and Rowe, 1986) but for which no production was reported for the years or from the sources covered in this report (shaded areas). The absence of production records for early years may result in an

understatement of reported cumulative production for other Charlotte quadrangle counties than those indicated here. A, Copper (309). B, Iron ore (310). C, Lead (311). D, Tin (321). E, Zinc (325). Numbers in parentheses represent the commodity code (see table 7).

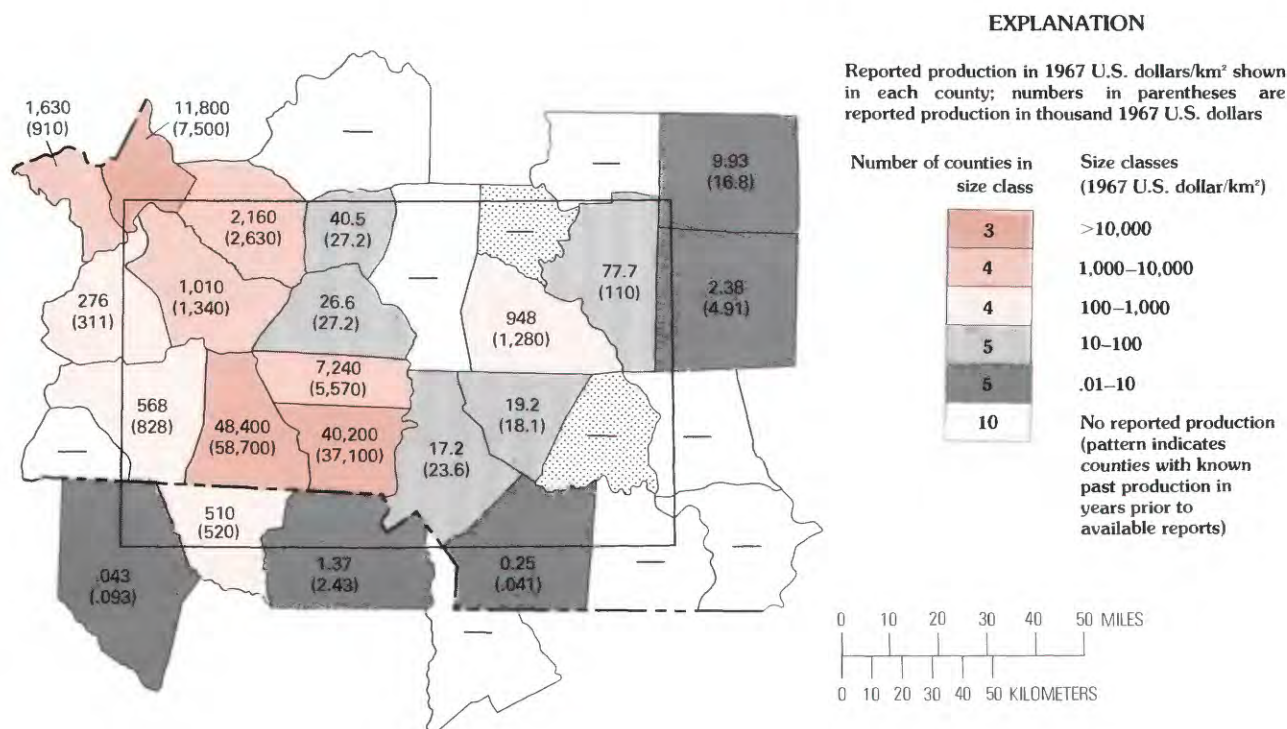


FIGURE 42.—Cumulative reported production for the metals (excluding the gold and silver (300) category) from the 31 Charlotte quadrangle counties. The time period of production, 1880–1978, is for reported mineral production, but production was not necessarily continuous during the period. Counties for which past metal producers within the Charlotte quadrangle

boundaries have been identified (D'Agostino and Rowe, 1986) but for which no production was reported for the years or from the sources covered here are indicated by a pattern. The absence of production records for early years may result in an understatement of reported cumulative production for other Charlotte quadrangle counties than those indicated here.

counties in the Charlotte quadrangle took place in the 1800's, but no consistent statistical records of this early production were available for this study (fig. 41C).

LITHIUM (312)—TIME PERIOD OF PRODUCTION RECORDS: 1938 TO 1978

Spodumene-bearing pegmatite dikes in the Kings Mountain belt are the principal source of the world's lithium. Production in Cleveland and Gaston Counties, N.C., was reported as early as 1938, and production has been continuous since 1951 in Cleveland County and since 1969 in Gaston County. Some production came from Lincoln County, N.C., during the mid-1950's (see fig. 43).

Lithium production has been reported in tons of spodumene, lithium minerals, and lithium (the terms "spodumene" and "lithium minerals" have been used synonymously in USBM reports). Because the computer programs used to calculate urw simply sum the physical units associated with the commodity code (312), it was necessary to convert all production data for spodumene and lithium minerals to contained lithium. A conversion factor of 2.88 percent lithium per ton of spodumene was

obtained from records of the late 1950's and early 1960's where both physical measures were reported. Production was apportioned among producing counties in the mid-1950's on the basis of reported total production and field observations of pits in each county that were operated during that period.

MANGANESE ORE (314)—TIME PERIOD OF PRODUCTION RECORDS: 1886 TO 1978

Manganese ore includes material reported as manganese, manganese ore, and manganiferous ore. Most of the production in the Charlotte quadrangle was from counties in the Kings Mountain belt. Residual manganese oxide (generally psilomelane or clayey pyrolusite) from a unit of the Battleground Formation has been used as pigment in brick clay. At the North Cove mine, McDowell County, N.C., in the Blue Ridge belt, manganese ore was produced from rocks of the Chilhowee Group.

THORIUM ORE (320)—TIME PERIOD OF PRODUCTION RECORDS: 1887 TO 1910

Most reported thorium ore production is from monazite- and zircon-bearing placer deposits; thorium

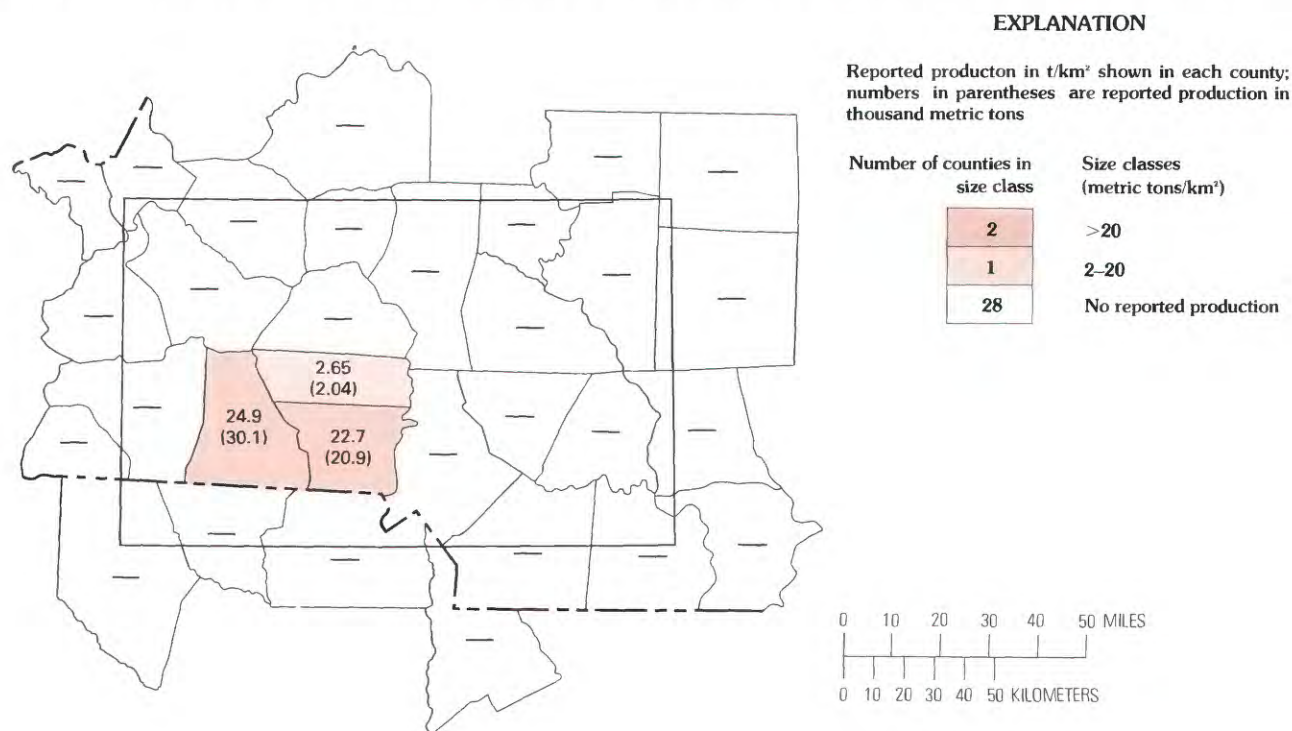


FIGURE 43.—Cumulative reported production for lithium (312) through 1978 from the 31 Charlotte quadrangle counties. The time period of production, 1938–1978, is for reported mineral production, but production was not necessarily continuous during the period.

ore production includes rare-earth sands consisting of mixed zircon, columbite, and samarskite, produced in 1902. Monazite has been produced chiefly from stream gravels in the Inner Piedmont belt; small production has been from gravels in Alexander, Catawba, and Lincoln Counties, N.C., although these counties are not shown as having had producing deposits on the location map of thorium production (D'Agostino and Rowe, 1986). Reported monazite production from Spartanburg County, S.C., is probably from deposits that are outside the Charlotte quadrangle. Rare earths were produced from pegmatites in the Blue Ridge belt (Mitchell County, N.C.), outside the Charlotte quadrangle.

TIN (321)—TIME PERIOD OF PRODUCTION RECORDS: 1903 TO 1944

Tin (cassiterite) mining in the Charlotte quadrangle took place in counties partly or entirely in the Inner Piedmont belt. Production was from pegmatites close to the contact with the adjacent Kings Mountain belt or from placer deposits. Most tin production took place in the 1800's; records of this production by county were not available (fig. 41D).

TITANIUM (322)—TIME PERIOD OF PRODUCTION RECORDS: 1942 TO 1952

Reported production is from a high-grade lode deposit (Broadhurst, 1955, p. 26) of granular ilmenite occurring

in the Wilson Creek Gneiss of the Blue Ridge belt. Titanium dioxide (TiO₂) concentrates were produced from the saprolitic overburden of the Yadkin River Valley (Richlands Cove) deposit (Caldwell County, N.C.) for use in the manufacture of titanium-based pigments. Production for the time period reported took place outside the Charlotte quadrangle.

ZINC (325)—TIME PERIOD OF PRODUCTION RECORDS: 1912 TO 1913

Reported production of zinc is from the Silver Hill mine (Davidson County, N.C.) in 1912 and 1913. Most zinc production in the Charlotte quadrangle, however, took place prior to the collection of consistent statistical records (fig. 41E), and zinc contained in lead or lead-silver ores mined in the early and middle 1800's commonly was discarded with mine or mill wastes.

NONMETALLIC MINERALS (400)

Nonmetallic minerals rank second, behind construction materials, in value of reported production from Charlotte quadrangle counties through 1978 (table 10), accounting for 13 percent of total value of mineral commodities (fig. 44). A major portion (79 percent) of the nonmetallic mineral production value is derived from feldspar that was produced mainly in parts of Mitchell County, N.C., outside the quadrangle. The second rank-

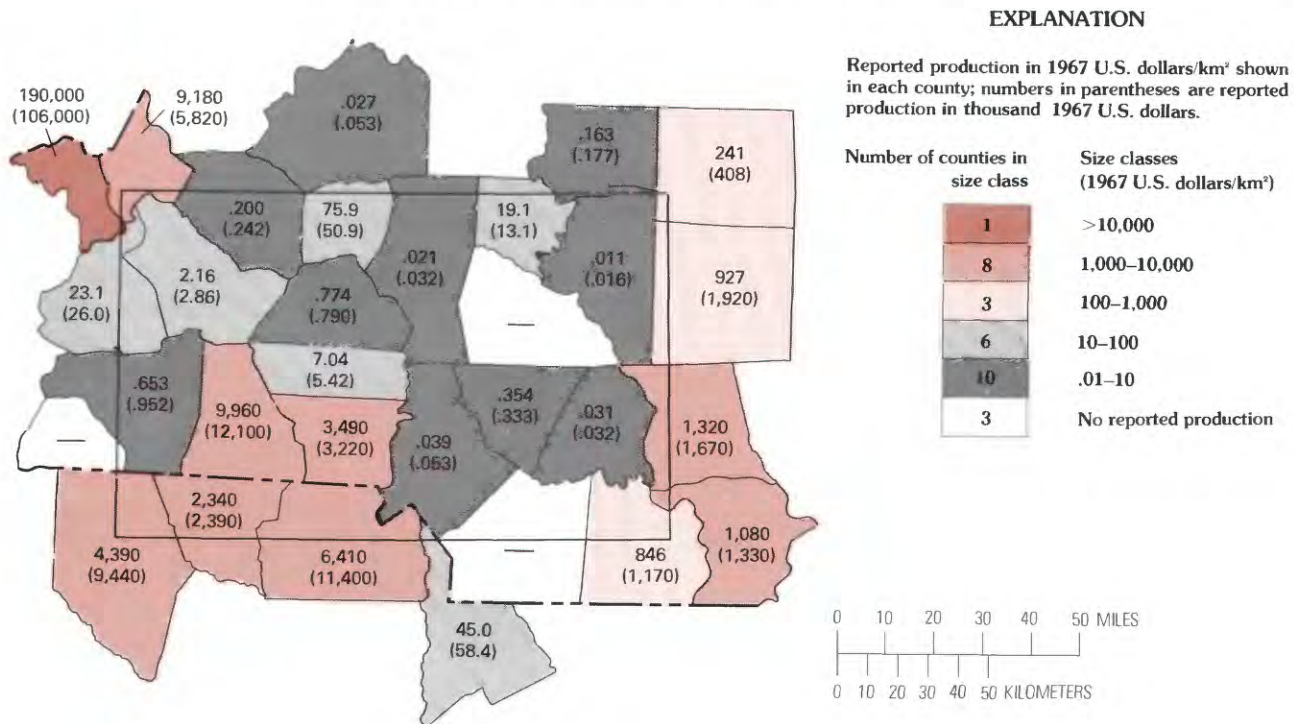


FIGURE 44.—Cumulative reported production for the nonmetallic minerals (400) category from the 31 Charlotte quadrangle counties. The time period of production, 1867–1978, is for reported mineral production, but production was not necessarily continuous during the period. D'Agostino and Rowe (1986) have indicated sites of past production of barite from Cleveland

County, N.C., and York County, S.C., but no production was reported in these counties by the data sources used for this study. For these and other counties having no reported production despite actual production or having an incomplete record of production, totals in this compilation underestimate total production.

ing nonmetallic mineral commodity, kyanite, produced in York County, S.C., accounts for about 7 percent of nonmetallic mineral production. Other commodities that each account for more than 1 percent of nonmetallic mineral production value are kaolin and specialty clays, industrial sands, vermiculite, barite, and talc. Phosphate rock, which is the major nonmetallic mineral that has been produced in North Carolina and South Carolina, has not been produced in the Charlotte quadrangle counties.

The comparison of all nonmetallic mineral production in the two States (fig. 36D) shows that the value of production from the Charlotte quadrangle counties is less than that of counties entirely outside the quadrangle. Production per unit area of nonmetallic minerals from the 27 Charlotte quadrangle counties in North Carolina has been 60 percent greater than that from the other 73 counties in that State; in South Carolina, nonmetallic mineral production per unit area from the four Charlotte quadrangle counties has been 28 percent less than that of the other 42 counties (fig. 37D).

KYANITE (401)—TIME PERIOD OF PRODUCTION RECORDS: 1939 TO 1969

Most reported kyanite production is from kyanite quartzites of the Kings Mountain belt at the Henry Knob mine, York County, S.C., where kyanite (and byproduct pyrite) production was reported for the 1950's and 1960's.⁷

BARITE (402)—TIME PERIOD OF PRODUCTION RECORDS: 1891 TO 1968

Barite has been produced in the Charlotte quadrangle from quartz-sericite schist in the Kings Mountain belt. The largest producer, Kings Creek mine in Cherokee County, S.C., was in operation from 1923 to 1966. Production was reported from Gaston County, N.C., for the late 1800's and early 1900's. Records of barite production prior to 1889 are not available.

⁷Statewide totals for kyanite include small amounts of staurolite.

KAOLIN AND SPECIALTY CLAYS (406)—TIME PERIOD OF PRODUCTION RECORDS: 1897 TO 1978

The kaolin and specialty clays commodity includes fire clay, fuller's earth, and kaolin; materials used in making paper, refractories, and ceramics; and materials used as absorbents or thickeners. This commodity also includes "marl," "calcareous marl," and "greensand marl." These materials are classified as nonmetallic minerals in contrast to common clay and shale, which are classified as construction materials. Most reported production is from counties in the Kings Mountain and Blue Ridge belts. Reported production from Guilford, Mitchell, and Richmond Counties, N.C., is probably from outside the Charlotte quadrangle.

FELDSPAR (408)—TIME PERIOD OF PRODUCTION RECORDS: 1911 TO 1978

Sodium-rich feldspar and potassium feldspar have been produced, along with mica, from granites and pegmatites of the Blue Ridge belt (Spruce Pine district), Inner Piedmont belt, and Kings Mountain belt. Some production from the Kings Mountain belt (Cleveland and Gaston Counties, N.C.) has been a byproduct of spodumene mining. Reported production for Avery, Forsyth, and Mitchell Counties, N.C., and for Spartanburg County, S.C., is from outside the Charlotte quadrangle. Production from within the quadrangle constitutes no more than about 11 percent of the total reported production from the Charlotte quadrangle counties.

GEMSTONES (411)—TIME PERIOD OF PRODUCTION RECORDS: 1900 TO 1978

Reports of gemstone production from North Carolina and South Carolina include several types of precious and semiprecious stones and mineral specimens. Reported production includes commercial ventures as well as some estimates of value of materials collected by rock hounds. Gemstone production has not been reported consistently in physical units; thus, the cumulative production is presented only in value units (1967 dollars).

Gemstone deposits in several parts of North Carolina are operated as tourist attractions. Gemstones produced from Charlotte quadrangle counties include hiddenite and emerald from the Hiddenite area in Alexander County, N.C., and emerald and aquamarine from the Spruce Pine area in Mitchell County, N.C. Other minerals, gems, and rocks that have been included in various reports of value of gemstones produced in North Carolina and South Carolina are actinolite, agate, amethyst, beryl, corundum, diamond, epidote, feldspar, garnet, kyanite, malachite, moonstone, olivine, opal, quartz, rhodolite, rhodonite, ruby, rutile, sapphire, serpentine, topaz, tourmaline, and unakite. Reported production of

gemstones for Avery, Forsyth, Guilford, Mitchell, Montgomery, Randolph, and Wilkes Counties, N.C., and Lancaster and Spartanburg Counties, S.C., is probably from deposits that are outside the Charlotte quadrangle.

GRAPHITE (412)—TIME PERIOD OF PRODUCTION RECORDS: 1895 TO 1916

Reported production of low-grade amorphous graphite is from Catawba and McDowell Counties, N.C., probably from interlayered mica schist and biotite gneiss within the Inner Piedmont and Blue Ridge belts.

LIME (413)—TIME PERIOD OF PRODUCTION RECORDS: 1894 TO 1976

The lime commodity includes lime, limestone, and "shell" used for agricultural and chemical purposes and for cement production. Since the 1950's, most such material has been reported as limestone used as a construction material and has been classified as stone. Reported production is from quarries in the Kings Mountain belt. The Limestone Springs quarry (Gaffney Marble Member of the Blacksburg Formation) in Cherokee County, S.C., is the principal producer. Reported production from Spartanburg County, S.C., is from quarries that are outside the Charlotte quadrangle.

PYRITE (419)—TIME PERIOD OF PRODUCTION RECORDS: 1900 TO 1969

Pyrite mining was reported from the Charlotte quadrangle as early as 1865, but production statistics adequate for this compilation were not recorded until the years indicated. Most production has been from the Kings Mountain belt in North Carolina. Reported production for Gaston County, N.C., in the early 1900's was from quartz-sericite schists at the Oliver mine. Pyrite also was produced as a byproduct of kyanite mining at Henry Knob in York County, S.C., in the 1960's. Reported production from Lancaster County, S.C., in 1918 is from outside the Charlotte quadrangle.

INDUSTRIAL SANDS (421)—TIME PERIOD OF PRODUCTION RECORDS: 1902 TO 1959

The industrial sands category includes crushed quartz and olivine used as foundry sand. Most reported production of other specialty or industrial sands is included in totals for sand and gravel used mainly for construction purposes and is included in statistics for sand and gravel. Most of the reported production of crushed quartz is from the Blue Ridge and Kings Mountain belts and the Triassic basin; reported production from Anson, Avery, Guilford, Mitchell, Montgomery, and Randolph Counties, N.C., is probably from outside the Charlotte quadrangle.

The reported production of olivine is from the Blue Ridge belt and also is outside the Charlotte quadrangle.

TALC (424)—TIME PERIOD OF PRODUCTION RECORDS:
1898 TO 1977

The reported production of talc and pyrophyllite (principally soapstone) has been from the Blue Ridge belt and from Montgomery and Randolph Counties, N.C., in the Carolina slate belt, all from outside the Charlotte quadrangle.

VERMICULITE (425)—TIME PERIOD OF PRODUCTION
RECORDS: 1956 TO 1962

The reported production of vermiculite from Guilford County, N.C., and Spartanburg County, S.C., is from outside the Charlotte quadrangle.

PRECIOUS METALS (500)

When North Carolina was a national leader in gold production in the early 19th century, a number of counties in the Charlotte quadrangle were important producers of gold (Koschmann and Bergendahl, 1968, p. 211). The importance of the Charlotte quadrangle counties is not well reflected in this analysis because early production data (1804–80 for North Carolina and 1826–80 for South Carolina) are available only as State totals that are in the undistributed category. The undistributed category accounts for 66 percent of the value of precious-metals production from North Carolina and 22 percent from South Carolina (fig. 36E); most of this production was prior to 1881. Gold has been the principal precious metal produced in the Carolinas and accounts for more than 97 percent of the value of precious-metals production from Charlotte quadrangle counties (table 10).

The precious metals category is the fourth-ranking of the five mineral commodity categories in value of mineral production from Charlotte quadrangle counties, contributing about 2 percent of total production value. Gold ranks seventh in production value among the commodities shown in table 10, but only about half of the value came from production within the quadrangle boundaries. However, if it were possible to estimate the amount of the undistributed production from the Charlotte quadrangle and the amount of unreported production (which is a more significant problem for gold than for other minerals), gold would probably rank higher among commodities produced in the quadrangle.

The value of precious-metals production per unit area in the North Carolina counties of the Charlotte quadrangle is 17 times that in other counties of the State, and in the South Carolina counties in the quadrangle it is 119

times that of other counties in that State (fig. 37E). The main reason for the dominance of precious-metals production by the South Carolina counties in the quadrangle is the relatively large production from the Haile mine in Lancaster County (fig. 45); this mine is in the part of the county that is outside the Charlotte quadrangle. To better show the importance of precious-metals production in the Charlotte quadrangle counties, undistributed values for all of North Carolina and South Carolina should be excluded, and values per unit area for the 31 counties of the quadrangle should be grouped together (\$686/km²) and compared with that of the North Carolina and South Carolina counties not in the quadrangle (\$21/km²).

The collection of production data for gold presents special problems owing to missing data or unreported production; the existence of data from several sources for some years; and, in some years, combined reporting of the value of gold and silver. Several authors have mentioned the problem of missing or understated production. Carpenter (1976, p. 14) stated that "no records were kept during the early years, and the first published sources of information were reports of the Director of the Mint. The mint records included only gold sent to the mint and did not include gold used for ornamental and jewelry purposes and gold sent abroad." Pardee and Park (1948, p. 29) noted that "scanty" records were kept during the early years of mining and that \$18,975,045 was "arbitrarily added" to the USBM and USGS total for gold in 1914, probably to account for early production that "had been used in the arts or shipped abroad, or had otherwise escaped the notice of the Mint." This addition increased the 1914 cumulative total to \$50,689,568 (Dunlop, 1916, p. 142). The practice of summing dollar values obtained in the years when production took place (current dollars) without regard for the time value of money was common in early reports of USGS and USBM, not only for gold, which had a fixed nominal price for many years, but for other mineral commodities. The practice for precious metals has continued at least through 1960. Pogue (1910, p. 96) and Graton (1906, p. 94) also commented on the lack of early production records and the impossibility of obtaining accurate estimates of precious-metals production for mines or districts. However, these observations are generally applicable to production records of all of the commodities being considered here.

One of the problems encountered in building a file on precious-metals production is conflicting published and unpublished data. As an example, table 11 presents conflicting 1905 North Carolina county gold production data from the Economic Papers series of the State of North Carolina (Pratt, 1907, p. 12) and the annual

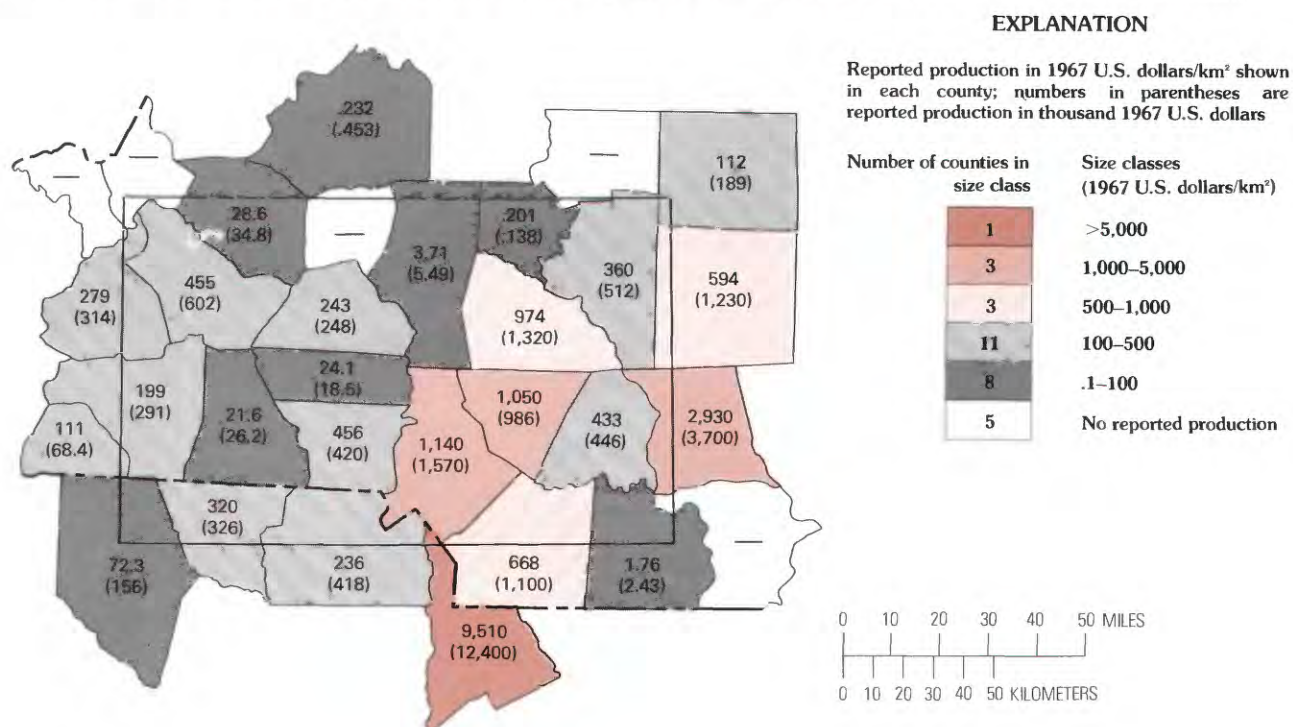


FIGURE 45.—Cumulative reported production for the precious metals (500) category from the 31 Charlotte quadrangle counties. The time period of production, 1804–1978, is for reported mineral production, but production was not necessarily continuous during the period.

precious metals report of the Director of the Mint (Pope, 1906, p. 105). Production value differences of greater than \$900 for each of nine counties and in the unknown-miscellaneous category can be seen in the two publications. The State reported production for 12 counties and the Mint for 11 of these counties and for 12 additional counties. The total production value for 1905 reported by the State is \$129,153 and by the Mint, \$123,895.98, a difference of about 4 percent. Percentage and absolute differences are much higher for some individual counties. For instance, the State reported \$10,000 of gold production from Stanly County in 1905, whereas the Mint reported only \$599.33, but the Mint reported \$10,872.13 for Randolph County, and the State reported no production value. Great precision is suggested by the Mint data (which, for many years, were listed to the thousandth of a troy ounce) which certainly is not justified.

The USBM microfilm records for gold production in 1905 (original records collected by the USGS) show a total production value of only \$98,716 for North Carolina, prior to the revisions and additions in 1914 mentioned above. Other published North Carolina totals for 1905 are \$125,685 (Pardee and Park, 1948, p. 31) and \$149,369⁸ (Hammett, 1966, p. 15). But even the sum of

TABLE 11.—Comparison of 1905 gold production records for counties of North Carolina from two published sources
[In current dollars; dash (—), no reported production]

County	Source	
	Pratt (1907, p. 12)	Pope (1906, p. 105)
Anson	\$ —	\$ 18.35
Burke	1,000	521.40
Cabarrus	22,836	17,927.81
Caldwell	—	741.10
Catawba	3,500	6,058.27
Cherokee	—	127.84
Cleveland	—	704.97
Davidson	1,000	14.66
Gaston	—	85.20
Guilford	9,000	807.57
Lincoln	—	11.89
McDowell	500	1,034.38
Mecklenburg	4,200	2,531.25
Montgomery	61,000	60,035.44
Moore	—	60.38
Nash	2,000	—
Person	—	909.48
Polk	—	64.06
Randolph	—	10,872.13
Rowan	7,200	5,094.66
Rutherford	—	239.05
Stanly	10,000	599.33
Union	4,948	5,510.62
Warren	—	512.80
Unknown-miscellaneous	1,969	9,413.34
Total	\$129,153	\$123,895.98

⁸Attributed by Hammett to the USBM.

the larger estimates of production value for each of the counties in table 11 (and the smaller estimate for miscellaneous) falls about \$1,700 short of Hammett's figure.

The procedural problem of conflicting data on gold production was resolved by using State totals from Pardee and Park (1948) for the years prior to 1881, Mint records for 1881 to 1905, and USBM microfilm records for 1906 to 1978, without eliminating the uncertainty and lack of precision that characterize the data.

The Mint records for 1881 to 1892 present another problem because production value is reported for precious metal and not for gold and silver separately. However, annual State production totals during that period (value and ounces) are presented separately for gold and silver. An additional problem is the combining of data from some counties in the Mint reports for 1881 to 1888. Also, in some annual reports, silver has been reported in terms of market value and in others, in terms of coining value. These problems were resolved by first apportioning dollar values among counties from which data had been combined according to ratios of gold and silver production value in these counties in subsequent years. Then a ratio (R) of gold to silver ounces was calculated for each county for cumulative production from 1893 through 1905, and the following algorithm was used to estimate gold and silver production for each year: Given:

$\$_c$ = value of precious metal production by county
 $\$_{Au,S}$ = State total gold value
 $oz_{Au,S}$ = State total gold ounces
 $\$_{Ag,S}$ = State total silver value
 $oz_{Ag,S}$ = State total silver ounces

Metal prices (P):

$$P_{Au} = \frac{\$_{Au,S}}{oz_{Au,S}} \quad P_{Ag} = \frac{\$_{Ag,S}}{oz_{Ag,S}}$$

For each county (subscript c):

$$\$_c = P_{Au} \times oz_{Au,c} + P_{Ag} \times oz_{Ag,c}$$

Assume:

$$\frac{oz_{Au,c}}{oz_{Ag,c}} = R \text{ (if } oz_{Ag,c} = 0 \text{ for 1893-1905, set } R = 10^{10})$$

Then:

$$oz_{Au,c} = \frac{\$_c}{P_{Au} + P_{Ag}/R}$$

$$\begin{aligned} \$_{Au,c} &= oz_{Au,c} \times P_{Au} \\ \$_{Ag,c} &= \$_c - \$_{Au,c} \\ oz_{Ag,c} &= \$_{Ag,c} / P_{Ag} \end{aligned}$$

R was assumed to be the same as the 1893 to 1905 average, but this is not strictly true, so the calculations

result in the sum of county gold values not equaling total values for a State. If the sum of calculated county gold values is greater than the reported State gold value by a certain amount, the sum of calculated county silver values is less than the reported State silver value by the same amount. When the gold sum is less than the gold total, the silver sum is greater than the silver total by a compensating amount. The totals calculated above can be corrected to the values marked with asterisk (*) superscripts by using the following formulas:

In cases where $\sum_c \$_{Au,c} > \$_{Au,S}$:

$$\$_{Au,c}^* = \$_{Au,c} \times \frac{\$_{Au,S}}{\sum_c \$_{Au,c}} \quad (1)$$

$$oz_{Au,c}^* = \frac{\$_{Au,c}^*}{P_{Au}}$$

$$\$_{Ag,c}^* = \$_c - \$_{Au,c}^*$$

$$oz_{Ag,c}^* = \frac{\$_{Ag,c}^*}{P_{Ag}}$$

In cases where $\sum_c \$_{Au,c} < \$_{Au,S}$:

$$\$_{Ag,c}^* = \left[\frac{\$_c}{P_{Au} \times R + P_{Ag}} \times P_{Ag} \right] \frac{\$_{Ag,S}}{\sum_c \$_{Ag,S}} \quad (2)$$

$$oz_{Ag,c}^* = \frac{\$_{Ag,c}^*}{P_{Ag}}$$

$$\$_{Au,c}^* = \$_c - \$_{Ag,c}^*$$

$$oz_{Au,c}^* = \frac{\$_{Au,c}^*}{P_{Au}}$$

GOLD (502)—TIME PERIOD OF PRODUCTION RECORDS:
1804 TO 1971

Reported production of gold is mainly from counties that straddle the boundary between the Charlotte belt and the Carolina slate belt (Gold Hill shear zone) and from counties in the South Mountains area (Burke County and vicinity) (fig. 38). All reported production from Lancaster County, S.C. (Haile mine), and most reported production from Montgomery County, N.C. (Iola mine), is from outside the Charlotte quadrangle, as is reported production from Anson, Guilford, Polk, and Wilkes Counties, N.C., and Spartanburg County, S.C. Only data from annual county production reports since

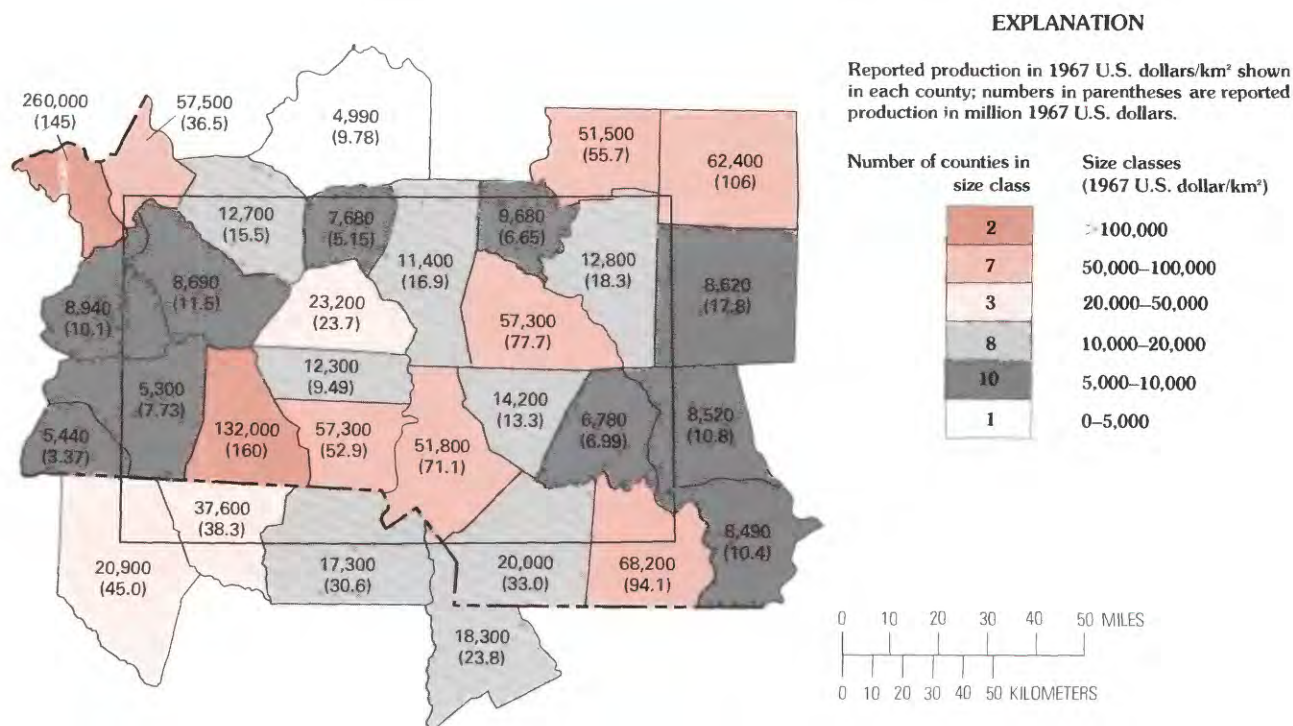


FIGURE 46.—Cumulative reported production for the all commodities (600) category from the 31 Charlotte quadrangle counties. The time period of production, 1804–1978, is for reported mineral production, but production was not necessarily continuous during the period.

1881 are included in the cumulative totals shown in figure 38.

Gold production from the Haile mine has been estimated at 278,000 oz or 87 percent of all gold production in South Carolina (Koschmann and Bergendahl, 1968, p. 231–232). Lancaster County production records for 1881–1978 (the records used in this study) include 5,040 kg (162,000 oz), almost all from the Haile mine. This is 85 percent of reported production attributed to specific South Carolina counties; that is, not including undistributed State production. As noted earlier, the large gold production from the Haile mine explains the high urv for precious metals in Lancaster County but does not pertain to the part of the county within the Charlotte quadrangle.

SILVER (504)—TIME PERIOD OF PRODUCTION RECORDS: 1881 TO 1971

Most reported silver production has been derived from gold and copper ores mined in counties that straddle the boundary between the Charlotte belt and the Carolina slate belt. In addition, some silver production reported during the late 1800's and early 1900's came from silver-lead ores of the Cid district (Davidson County). All or most of the reported production from Anson, Guilford,

Montgomery, Polk, Randolph, Union, and Wilkes Counties, N.C., and from Lancaster (Haile gold mine) and Spartanburg Counties, S.C., is from outside the Charlotte quadrangle.

SUMMARY FOR ALL MINERAL COMMODITIES (600)

The cumulative reported value of mineral production for the 31 Charlotte quadrangle counties is \$1.17 billion (1967 dollars), which represents 30 percent of reported mineral production for North Carolina and South Carolina combined (see fig. 36F). The distribution of this production by county are shown in figure 46. Cleveland, Mitchell, Guilford, and Anson Counties, N.C., are the leading mineral-producing counties in the quadrangle; each has a cumulative reported production value in excess of \$90 million (1967 dollars) (table 12). However, Cleveland County is the only one of these counties in which most of the mineral production has been from within the Charlotte quadrangle.

The percentage of each county that occurs within the Charlotte quadrangle boundaries is shown in figure 47, and a ranking of Charlotte quadrangle counties by the value of cumulative reported mineral production. Several county totals include production data from parts of the counties outside the boundaries of the Charlotte

TABLE 12.—*Value of cumulative reported mineral production of all mineral commodities from each of the 31 Charlotte quadrangle counties*

[Percentages for each county may not add to 100.0 due to independent rounding. —, no reported production. The numbers in parentheses following the name of each commodity and commodity category are the codes used in the COMOD program]

County and State	Value (thousand 1967 U.S. dollars; rank in parentheses)	Value per unit area (1967 U.S. dollars/km ² ; rank in parentheses)	Percent of value accounted for by each commodity category				
			Construction materials (100)	Fuels (200)	Metals— excluding gold and silver (300)	Nonmetallic minerals (400)	Precious metals (500)
Cleveland, N.C.	160,000 (1)	132,000 (2)	56	—	37	7.5	0.02
Mitchell, N.C.	145,000 (2)	260,000 (1)	27	0.0007	.63	73	—
Guilford, N.C.	106,000 (3)	62,400 (4)	99	—	.02	.39	.18
Anson, N.C.	94,100 (4)	68,200 (3)	99	—	—	1.2	.003
Rowan, N.C.	77,700 (5)	57,300 (6)	97	—	1.7	—	1.7
Mecklenburg, N.C.	71,100 (6)	51,800 (8)	98	—	.03	.00007	2.2
Forsyth, N.C.	55,700 (7)	51,500 (9)	100	—	—	.0003	—
Gaston, N.C.	52,900 (8)	57,300 (7)	23	—	70	6.1	.80
Spartanburg, S.C.	45,000 (9)	20,900 (12)	79	—	.0002	21	.35
Cherokee, S.C.	38,300 (10)	37,600 (10)	92	—	1.4	6.2	.85
Avery, N.C.	36,500 (11)	57,500 (5)	63	—	21	16	—
Union, N.C.	33,000 (12)	20,000 (13)	97	—	.0001	—	3.3
York, S.C.	30,600 (13)	17,300 (15)	62	—	.008	37	1.4
Lancaster, S.C.	23,800 (14)	18,300 (14)	48	—	—	.25	52
Catawba, N.C.	23,700 (15)	23,200 (11)	99	—	.11	.003	1.0
Davidson, N.C.	18,300 (16)	12,800 (17)	97	—	.61	.00009	2.8
Randolph, N.C.	17,800 (17)	8,620 (24)	82	—	.03	11	6.9
Iredell, N.C.	16,900 (18)	11,400 (20)	100	—	—	.0002	.03
Caldwell, N.C.	15,500 (19)	12,700 (18)	83	—	17	.002	.22
Cabarrus, N.C.	13,300 (20)	14,200 (16)	92	—	.14	.002	7.4
Burke, N.C.	11,500 (21)	8,690 (23)	83	—	12	.02	5.2
Montgomery, N.C.	10,800 (22)	8,520 (25)	50	—	—	16	34
Richmond, N.C.	10,400 (23)	8,490 (26)	87	—	—	13	—
McDowell, N.C.	10,100 (24)	8,940 (22)	94	—	3.1	.26	3.1
Wilkes, N.C.	9,780 (25)	4,990 (31)	100	—	—	.0005	.005
Lincoln, N.C.	9,490 (26)	12,300 (19)	41	—	59	.06	.20
Rutherford, N.C.	7,730 (27)	5,300 (30)	86	—	11	.01	3.8
Stanly, N.C.	6,990 (28)	6,780 (28)	94	—	—	.0005	6.4
Davie, N.C.	6,650 (29)	9,680 (21)	100	—	—	.20	.002
Alexander, N.C.	5,150 (30)	7,680 (27)	98	—	.53	.99	—
Polk, N.C.	3,370 (31)	5,440 (29)	98	—	—	—	2.0

quadrangle; probably all or most of the reported mineral production from Anson, Forsyth, Guilford, Mitchell, Polk, Randolph, Richmond, and Wilkes Counties, N.C., and Lancaster and Spartanburg Counties, S.C., is from outside the quadrangle.

The 27 Charlotte quadrangle counties in North Carolina had 137 percent more mineral production per unit area than the State's other 73 counties, whereas the 4 Charlotte quadrangle counties in South Carolina produced 53 percent more per unit area than the other 42 counties in that State (see fig. 37F). Among the Charlotte quadrangle counties, Mitchell and Cleveland Counties, N.C., have produced considerably more value per unit area than any of the others (fig. 48). Calculated results for cumulative value and for cumulative value per unit area for each Charlotte quadrangle county are shown in table 12.

The contribution of each commodity category to each county's production total is shown by ranking the 31

Charlotte quadrangle counties according to the value of cumulative reported mineral production (fig. 49). This figure shows the predominance of construction materials (principally stone and sand and gravel) and nonmetallic minerals (mostly feldspar, kyanite, and kaolin and specialty clays). Mineral commodities from these two categories accounted for 88 percent of cumulative value of production from the Charlotte quadrangle counties (see table 10). Construction material is reported as having been produced in each of the 31 Charlotte quadrangle counties; for 22 of these counties, 80 percent or more of cumulative reported value of all mineral commodities is accounted for by construction materials; for 17 of these 22 counties, construction materials contribute more than 90 percent to the county total (table 12). Twenty-eight Charlotte quadrangle counties have reported mineral production in the nonmetallic minerals category. However, only three counties have cumulative production values of nonmetallic minerals exceeding 20 percent of

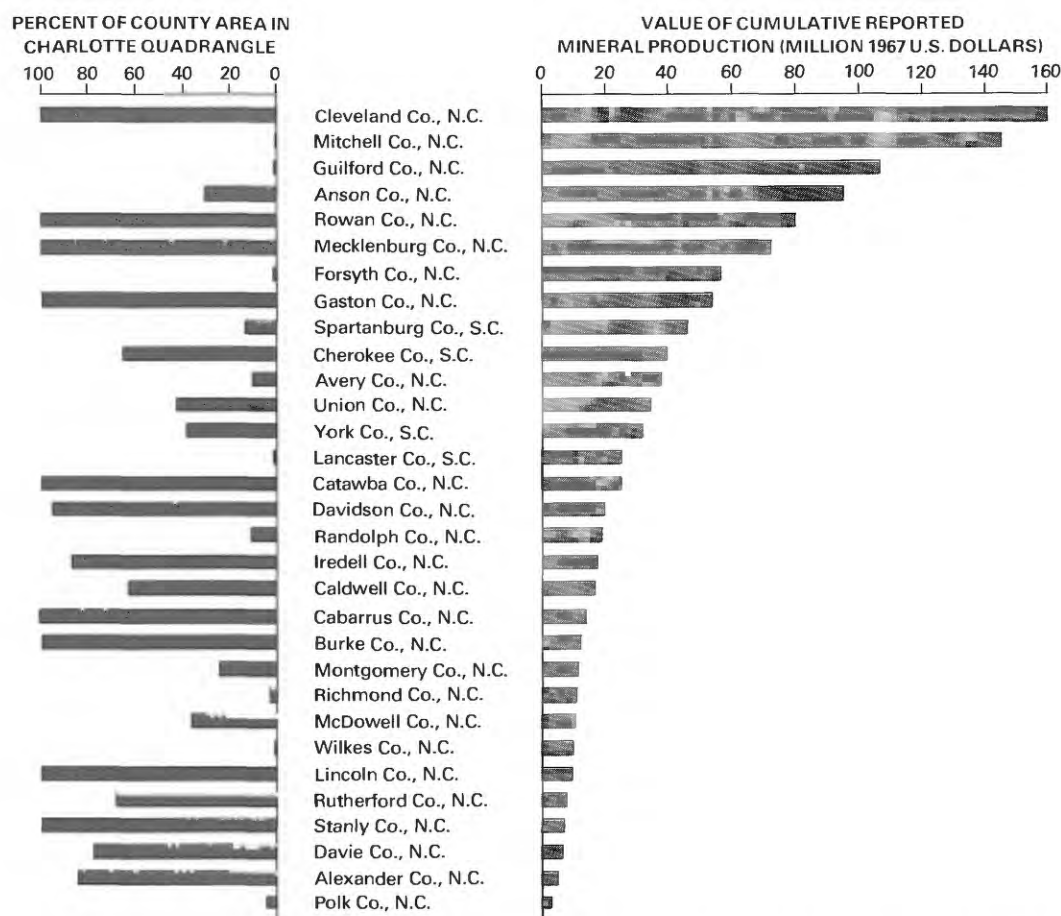


FIGURE 47.—Percent of each county's area that is within the Charlotte quadrangle and the cumulative constant dollar value of reported mineral production for Charlotte quadrangle counties.

the county totals (see table 12): Mitchell County, N.C., 73 percent of the total value (mostly feldspar); York County, S.C., 37 percent (mostly kyanite); and Spartanburg County, S.C., 21 percent (mostly feldspar and vermiculite). Virtually all production from Mitchell and Spartanburg Counties, however, is from outside the Charlotte quadrangle.

Mineral commodities whose reported production per unit area for the Charlotte quadrangle counties is more than twice that of the averages for North Carolina and South Carolina are mica, stone, iron ore, manganese ore, thorium ore, tin, titanium, zinc, kyanite, barite, feldspar, pyrite, and industrial sands (see table 13).

In 5 of the 10 leading Charlotte quadrangle counties, crushed and dimension stone contribute more than 80 percent of the cumulative constant dollar value (table 12). Sand and gravel account for 97 percent of the value from Anson County, N.C. Cleveland County, N.C., a producer of stone, lithium minerals, and mica, leads the 31 counties in value of cumulative mineral production (in 1967 dollars) with \$160,000,000; it ranks second in value

per unit area (urv) with \$132,000/km². Polk County, N.C., has the smallest total production (\$3,370,000) and ranks 29th in urv with \$5,440/km²; construction materials accounted for 98 percent of this value. Mitchell County, N.C., which ranks second in total production value (\$145,000,000) and first in urv (\$260,000/km², owes much of its cumulative value to feldspar and mica produced outside of the quadrangle (in the Spruce Pine district). The Anson County, N.C., totals (\$94,100,000—ranked fourth, and \$68,200/km²—ranked third) are almost entirely attributable to sand and gravel production from deposits outside the quadrangle. Stone production from Guilford County, N.C., was mostly from deposits outside the Charlotte quadrangle and accounted for 96 percent of its totals (\$106,000,000—ranked third, and \$62,400/km²—ranked fourth).

CONCLUSIONS

The estimation of past production of mineral raw materials from the Charlotte quadrangle has provided

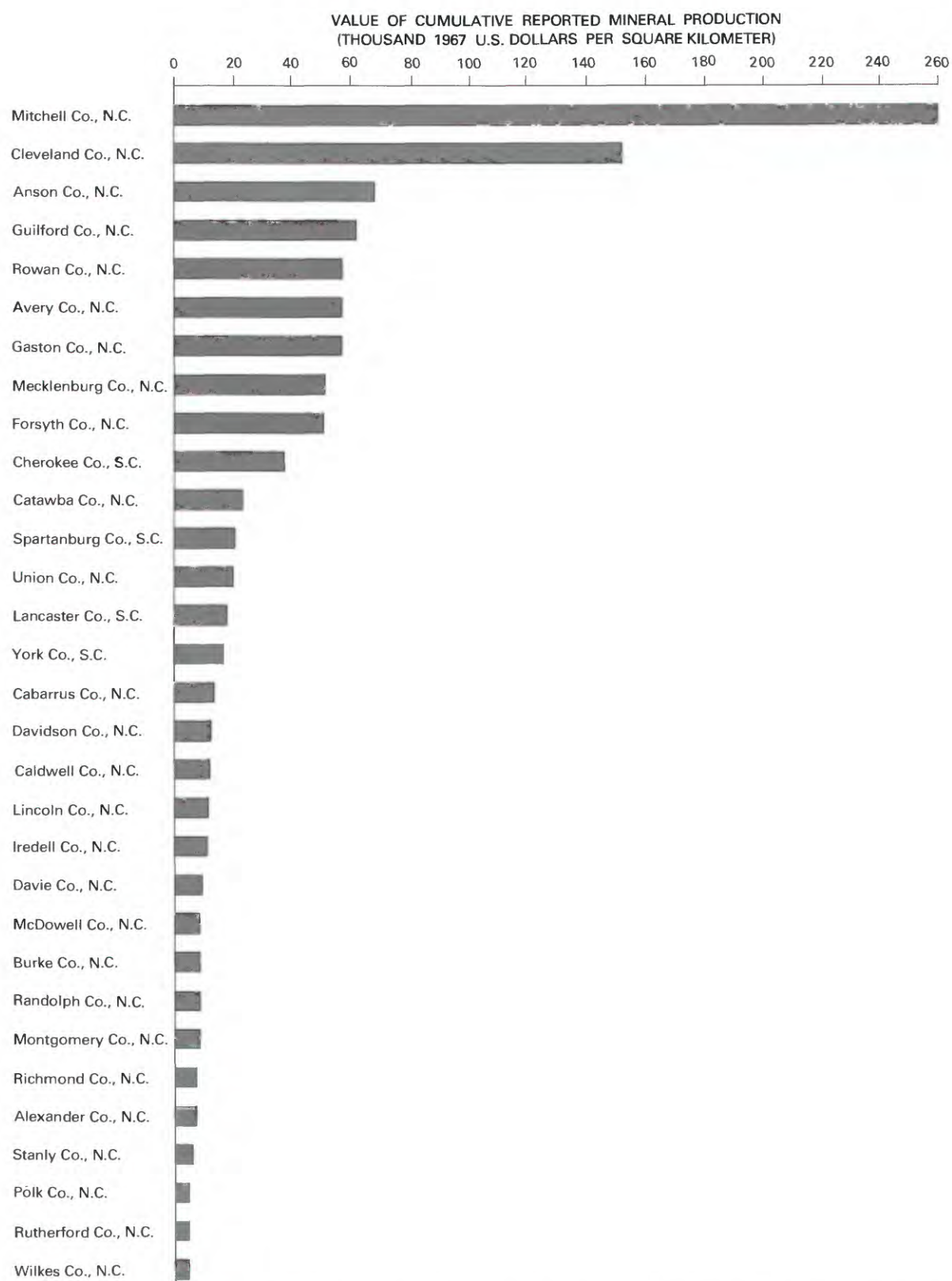


FIGURE 48. — Value of cumulative reported mineral production per unit area (thousand 1967 U.S. dollars per square kilometer) for the 31 Charlotte quadrangle counties.

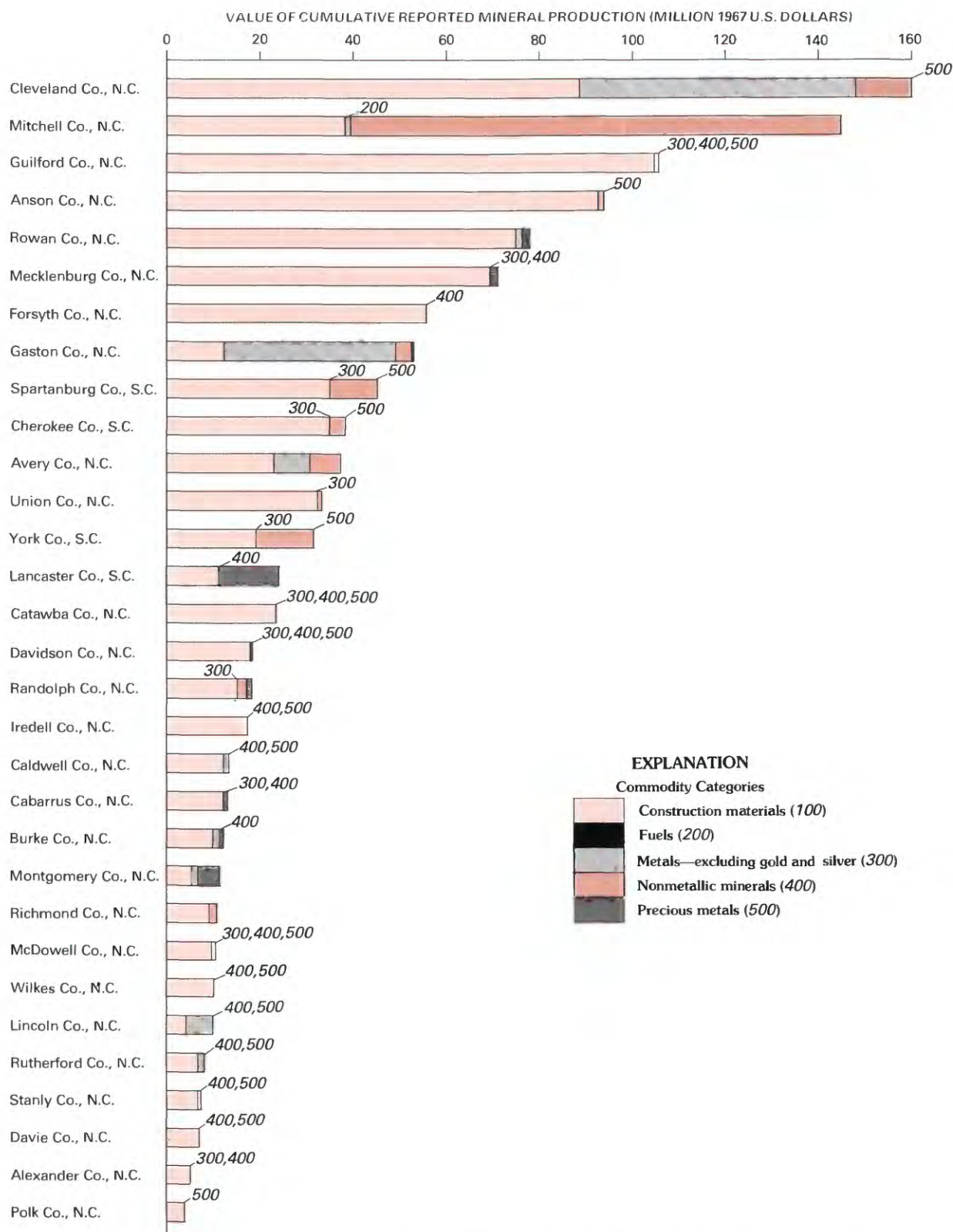


FIGURE 49.—Value of cumulative reported mineral production (million 1967 U.S. dollars) from the 31 Charlotte quadrangle counties. The codes of mineral commodity categories having production values too small to illustrate have been indicated by italics.

TABLE 13.—Quantity and quantity per unit area of reported mineral production through 1978 by commodity and commodity category from the 31 Charlotte quadrangle counties compared with quantity per unit area of production from North Carolina and South Carolina

Commodity category (code)	Commodity (code)	Reported production from Charlotte quadrangle counties (metric tons unless otherwise noted)	Reported production per unit area from Charlotte quadrangle counties (metric tons/km ² unless otherwise noted)	Reported production per unit area from North Carolina and South Carolina (metric tons/km ² unless otherwise noted) ¹
Construction materials (100): ²	Asbestos (101)	590	0.015	0.131
	Common clay and shale (103)	23,700,000	617	607
	Mica (106)	1,760,000	45.8	17.4
	Sand and gravel (107)	118,000,000	3,070	2,250
	Stone (108)	336,000,000	8,740	4,300
Fuels (200): ³	Uranium ore (211)	.017	.0000004	.00000008
Metals—excluding gold and silver (300): ⁴	Copper (309)	1,220	.032	.307
	Iron ore (310)	1,300,000	33.8	8.50
	Lead (311)	90.1	.002	.005
	Lithium (312)	53,100	1.38	.260
	Manganese ore (314)	47,500	1.37	.257
	Thorium ore (320)	4,580	.119	.024
	Tin (321)	38.4	.001	.0002
	Titanium (322)	63,700	1.98	.325
	Zinc (325)	138	.004	.0008
Nonmetallic minerals (400): ⁵	Kyanite (401)	187,000	4.88	.956
	Barite (402)	130,000	3.38	.832
	Kaolin and specialty clays (406)	573,000	14.9	130
	Feldspar (408)	10,700,000	280	62.3
	Gemstones (411)	108,000 ⁶	2.80 ⁷	2.53 ⁷
	Graphite (412)	406	.011	.274
	Lime (413)	54,100	1.41	6.13
	Pyrite (419)	32,800	.854	.189
	Industrial sands (421)	428,000	11.2	5.33
	Talc (424)	94,300	2.46	11.3
	Vermiculite (425)	4,100	.107	8.38
Precious metals (500): ⁸	Gold (502)	11,200 ⁹	.292 ¹⁰	.150 ¹⁰
	Silver (504)	6,860 ⁹	.179 ¹⁰	.156 ¹⁰

¹Because unit regional weights (urw) in this column include undistributed production (some of which may have been produced from Charlotte quadrangle counties), the importance of Charlotte quadrangle counties is in some cases understated in comparison.

²Reported production from Anson, Forsyth, Guilford, Mitchell, Polk, Randolph, Richmond, and Wilkes Counties, N.C., and Lancaster County, S.C., is probably from outside the Charlotte quadrangle.

³Reported production from Mitchell County, N.C., is from outside the Charlotte quadrangle.

⁴Reported production from Avery, Caldwell, Guilford, and Mitchell Counties, N.C., and Spartanburg County, S.C., is probably from outside the Charlotte quadrangle.

⁵Reported production from Anson, Davie, Forsyth, Guilford, Mitchell, Randolph, Richmond, and Wilkes Counties, N.C., and Lancaster and Spartanburg Counties, S.C., is probably from deposits that are outside the Charlotte quadrangle.

⁶1967 U.S. dollars.

⁷1967 U.S. dollars per square kilometer.

⁸Reported production from Anson, Guilford, Polk, and Wilkes Counties, N.C., and Lancaster and Spartanburg Counties, S.C., is probably from outside the Charlotte quadrangle.

⁹Kilograms.

¹⁰Kilograms per square kilometer.

information about the differences in importance of mineral production from the various counties in the quadrangle and has demonstrated the dominant role of mineral construction materials, especially stone and sand and gravel, in the total value of mineral production from the area. The results provide a basis for comparing the mineral production per unit area from parts of the

Charlotte quadrangle with that of other regions that have been developed to a similar extent.

Analysis of the distribution of mineral production requires the establishment of systems for classifying production data by area and commodity. As is evident from this study, problems that diminish the effectiveness of the study arise because the political boundaries used

for collection and analysis of production data do not coincide with the geologic boundaries resulting from earth-sciences studies. These problems are compounded by the fact that the quadrangle boundaries that define the study area are coincident with neither the geologic nor the county boundaries. Problems are created by showing production data by counties, but workable alternative area divisions for data collection are limited or nonexistent. It must also be recognized that the average production per unit area in a county is a method of representing areal diversity of production and does not indicate that all parts of a county should yield equal production of each mineral commodity.

The availability of production data is not always consistent with the commodity classes used in this study for the historical period studied. For example, it was mentioned earlier that recent sand and gravel totals include industrial sands along with construction materials.

The presentation of results in maps and tabular formats may impart a false sense of the precision associated with cumulative totals based on estimates from mineral industry canvasses, on published reports on production, and on the Wholesale Price Index. Finally, because of nonreporting of production, for whatever reason, the totals presented in this report are minimum estimates of production.

What guidance does the value of cumulative mineral production provide to those doing mineral exploration or mineral-resource assessments? Should one look for large undiscovered mineral deposits in areas that have supported large production in the past, or does high past production indicate depleted and less favorable terrain? These questions cannot be answered by production studies alone. Data such as those presented in this study, used in conjunction with other components of a mineral-resource assessment folio (especially geologic maps, inventories of identified resources, and geochemical surveys), may be extremely useful in answering questions about "how much" of a resource is present in an area. Information about the intensity and thoroughness of past exploration activities would also be very useful in evaluating the significance of an area's mineral production, but such information is generally unavailable or too sparse and inadequate to deduce an accurate picture of exploration history. The information implicit in production statistics results not only from the physical existence of minerals in a region but from the demands for these minerals that human activities have created over past years and from the historical reporting procedures for production data. Thus, the use of past production information as a guide to mineral-resource assessment requires much interpretation using knowledge not explicitly discussed in this report.

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